1973–1983

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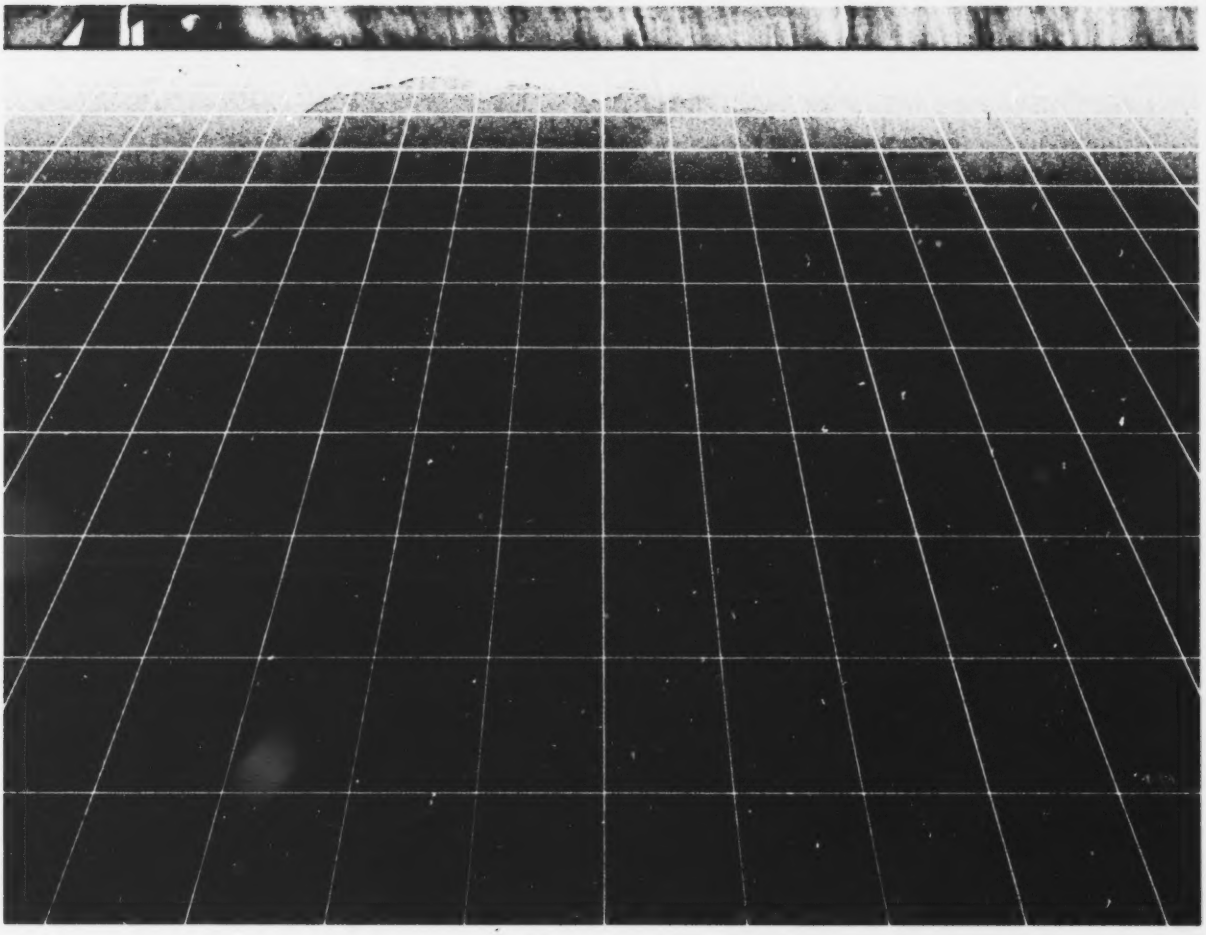
National Research Council Canada
Conseil national de recherches Canada

Building Research
1973–1983



Some of the laboratories of the Division of Building Research (centre of photo) located at NRC on Montreal Road in Ottawa

ISBN 0-660-11626-X
Building Research, 1973-1983
NRCC 23262
$5.00
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Ce document est aussi publié en français

PREFACE

This report describes the work and achievements of NRC's Division of Building Research and its contribution to the building industry over the past ten years.

Building research is not perceived as a glamourous activity. The spotlight is normally reserved for architects and builders. Their successes, however, are due in no small part to the labours of researchers who, working behind the scenes, bring creativity to the solution of building problems and the development of new technology.

An imposing array of challenges confronts the building industry. DBR is equal to the task, bringing to it a diversity of skills and facilities. Research projects are varied, from acoustical studies in the National Arts Centre to geotechnical engineering in the Beaufort Sea, from low-energy houses to energy-efficient skyscrapers, from heat pumps to tunnel-boring machines, from walls, windows and roofs to fibre-reinforced concrete, from smoke control in high buildings to snow loads on roofs. Many projects are long term, encompassing basic research. Solutions, often elusive, eventually unfold. Some research is more on the practical side and of short duration, though the results may be substantial.

Although the laboratory is the setting for most of the research, considerable time is devoted to field studies, particularly geotechnical work. Visits to construction sites and observations of performance problems in buildings figure prominently as well.

The factor that dominates building research in Canada is the harshness and variability of the climate. It has a major influence on design and causes many of the problems with existing buildings. To ignore it is to invite failure.

It is hoped that this report will demonstrate the diversity of research carried out by the Division from 1973 to 1983 and, more important, how DBR's achievements have led to better building and better buildings in Canada.

Carl B. Crawford
Director
Division of Building Research
National Research Council Canada
May 1984

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ABBREVIATIONS

The following abbreviations have been used in this report for some of the agencies and institutions that are referred to frequently:

ASHRAE – American Society for Heating, Refrigerating and Air-Conditioning Engineers

ASTM – American Society for Testing and Materials

CGSB – Canadian General Standards Board

CMHC – Canada Mortgage and Housing Corporation

CSA – Canadian Standards Association

DBR – Division of Building Research

EMR – Energy, Mines and Resources Canada

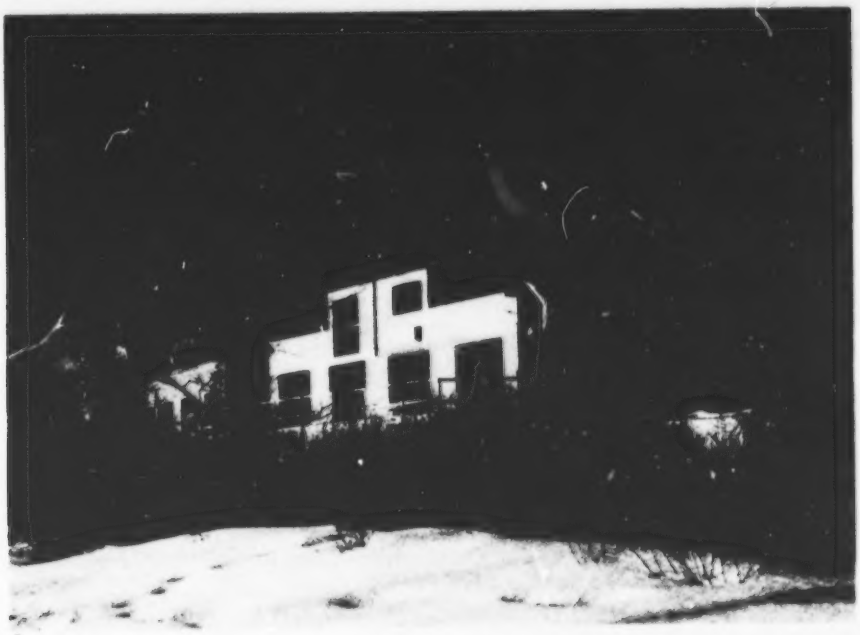
HUDAC – Housing and Urban Development Association of Canada

IEA – International Energy Agency

ISO – International Organization for Standardization

NBC – National Building Code

NRC – National Research Council



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1.
Dealing with building challenges, large or small, is a DBR specialty.

2.
Glass cladding has become increasingly popular in large buildings.

3.
Former Director N.B. Hutcheon makes a point in the technology transfer process.

4.
Scanning electron microscope. Modern equipment helps keep DBR in the forefront of research and technology development.

THE ROLE OF DBR

Conducting Research

Construction activity is a barometer of economic well-being in most western countries. When construction is healthy, so is the economy.

Good construction is founded on good technology. This technology comes from research. With construction accounting for up to 17% of Canada's Gross National Product, researchers have an awesome responsibility. To a large extent that responsibility rests with the Division of Building Research, established by the National Research Council in 1947. The Division's mandate is to provide a research service to the building industry and in so doing it plays a key role in economic development.

Research falls into several general categories. There is basic research on the properties, behaviour and durability of materials, and studies of processes, concepts and techniques, many of them drawing on the pure sciences. Improving the strength, workability and durability of concrete is one such pursuit. Then there is the more applied research, the study of building failures and problems in the field, and the resolution of the problems through new design guidelines. Spalling of masonry is an example. Another category is the testing of materials and components in the laboratory and in actual use, a particularly important service to the industry. Examples are wall and window tests.

A multi-disciplinary approach is usually necessary. Research on the effectiveness of a particular type of insulation, for example, is not complete without considering the question of fire safety. Similarly, airtightness in houses, while desirable from an energy-conservation point of view, cannot be achieved at the expense of acceptable air quality.

Putting Results into Practice

Once the research, development and testing have been completed, the next step is to make the information available to the industry. This is the all-important process of technology transfer — putting results into practice. The Division does this through publications, seminars, technical advice in response to inquiries and assisting with the preparation of codes and standards.

Research papers are published in scientific and technical journals or conference proceedings throughout the world. These papers are generally highly technical and are intended mainly for other researchers pursuing similar studies.

Information is disseminated to builders, engineers, architects, contractors and manufacturers through "building practice" publications. The most popular of these are Canadian Building Digests, four-page treatises on problems, concepts, materials and processes. Established in 1960, this series has a mailing list of over 20 000 and continues to gain popularity with the industry and teaching institutions. Complementing the Digests are numerous other reports, books and proceedings.

The Division of Building Research makes a major contribution to the National Building Code and the National Fire Code through research and advisory services. Office facilities and support for code committees are provided. DBR researchers also hold memberships in over 300 national and international standards-writing committees.

Working with the Industry

While publications are a major source of information, direct contact with the industry is an effective method of technology transfer. For this reason DBR's seminar workshop series, now called Building Science Insight, has been extremely popular. These seminars are held in major cities across the country on a timely subject each year.

Researchers have numerous discussions with individuals in the industry. Practitioners value advice direct from the

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source. This transfer of information through consultation takes place in the office, in the laboratory, on the job site or in the seminar room.

DBR staff serve on numerous committees supporting the building industry. The Division has a formal agreement to provide research and testing services on materials and systems for the Canada Mortgage and Housing Corporation. Many associations have close ties with the Division. These are often formalized through fellowships whereby a person from industry works in a Division laboratory for up to three years. To date there have been fellowships covering concrete, steel, brick, plastics and electrical aspects of buildings.

DBR's dual role of research and technology transfer is carried out by a team of 120 engineers, architects, and scientists from a range of disciplines, backed by a support staff of 160. The annual budget is now about $15 million.

The Division's headquarters are in Ottawa where the main laboratories are located. There are three regional stations, in Vancouver, Saskatoon and Halifax. The Saskatoon station has laboratory facilities; the others do not. All three have a responsibility to represent the Division, to respond to regional problems and to communicate research results to users.

A Fire Research Field Station at Carleton Place, Ontario, near Ottawa was opened in 1981. Rounding out the Division's facilities is the Avalanche Research Station at Revelstoke, B.C.

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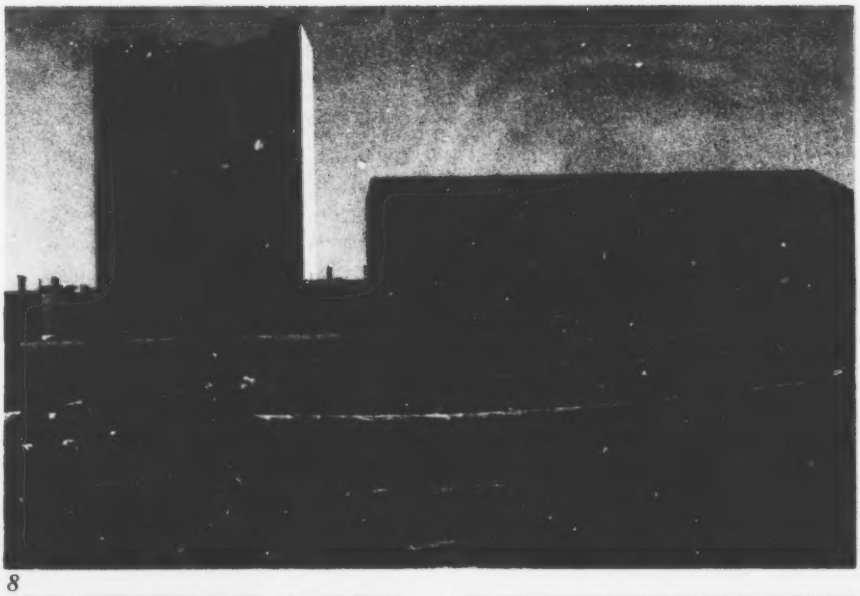

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6.
Air heating collector calorimeter developed at DBR for solar research.

7.
The old made new through rehabilitation, a common activity as Canada's building stock ages.

8.
DBR's Fire Research Field Station located near Ottawa has enhanced the study of fire and smoke movement in high-rise buildings.

9.
Damage caused by leakage of moist air into a stud wall cavity of a house.

1973-1983: THE CHANGING SCENE

Although DBR continues to provide a broad research and information service to the Canadian construction industry, the focus has changed to some extent in the past ten years to meet new demands and to reflect changing economic conditions. The major changes were in energy, fire research, building performance and technology transfer.

Energy Research

Ever since the oil crisis of 1973, energy research has been a priority for DBR because buildings account for about one third of total energy consumption. Improved thermal efficiency was an obvious step toward energy conservation and additional funds and positions were allocated for research into it and other energy matters.

The DBR environmental laboratory built in 1970 was enlarged in 1976 and became the centre for studies of the performance of windows and walls, the thermal properties of insulation and other building materials, and various aspects of ventilation, air quality and illumination.

Solar energy research was conducted in-house and through contracts. To accommodate this increased activity NRC set up a separate office, the Solar Energy Project, later taken over by the Council's new Division of Energy Research and Development.

Guidelines for energy conservation in residential and commercial buildings were published in "Measures for Energy Conservation in New Buildings," issued by the Associate Committee on the National Building Code.

Northern development projects called for research on pipeline construction, thermal insulation for highways, measurement of ice forces against wharves, and observations of the performance of ice platforms used for offshore drilling.

Technology Transfer

The formation of the Canadian Committee on Building Research in 1975 has led to better communication with the building industry. The committee provides an interdisciplinary forum for the stimulation and application of building science and technology in Canada. One of its first activities was to initiate, in cooperation with the industry, the triennial Canadian Building Congress. The first Congress, "Energy and Buildings", held in Toronto in 1976, attracted 600 participants. The second, "The Rehabilitation of Buildings," was held in October 1979, also in Toronto. Victoria was the site of the third Congress in October 1982, with the theme "Achievements and Challenges in Building."

Fire Research

Fire research is a complex subject and technology has been evolving slowly. Standard test methods have been developed to evaluate flammability and other fire aspects of conventional building materials, but correlation of test results and in-service performance is often poor. DBR has co-operated with the Underwriters' Laboratories of Canada and the U.S. National Bureau of Standards in developing test methods that are more representative of fire conditions in a building.

The opening of the new Fire Research Field Station west of Ottawa in 1981 satisfied a number of conditions that could not be met by the existing laboratory:

- a location where fire tests producing considerable smoke could be tolerated;
- a large enough facility to simulate more realistic fire conditions;
- a means to study the movement and control of smoke in tall buildings under winter conditions.

The station comprises a burn hall, a 10-storey tower, and a support services building. The burn hall, within an area of 1680 m^2, can accommodate a variety of full-scale fire set-ups.

The new column test furnace completed in 1980 at the Montreal Road site allows testing of full-size columns under load. It has been used extensively to confirm the validity of theoretical calculations for predicting the behaviour of building columns in a fire.

Because there had been little research in Canada on problems faced by the fire fighting services, NRC in 1982 established an Associate Committee to fill the void. This was in response to a brief submitted to NRC by the Association of Canadian Fire Marshals and Fire Commissioners and the Canadian Association of Fire Chiefs, and to a recommendation of an NRC-sponsored study on fire prevention and control systems in Canada.

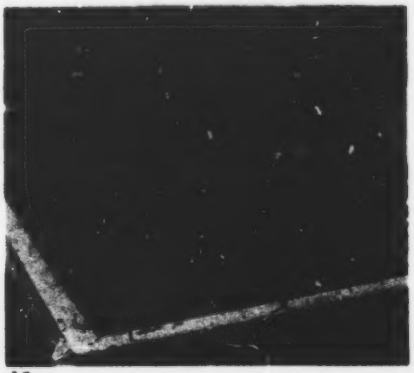
Building Performance

The technical aspects of a building such as the performance of roofs, walls and windows, and the human aspects such as user satisfaction in terms of convenience, safety, noise control and lighting both need to be studied for a proper appreciation of total performance. Performance is measured by assessing how well the building satisfies the needs of its owners and users and how well the components perform the functions for which they were designed. On the human side, DBR has studied crowd movement in buildings and sports stadiums, stair safety, the accessibility of buildings to the disabled, the behaviour of occupants in emergencies, and the design of washroom facilities in public buildings.

On the technical side, research on the basic properties and behaviour of materials and components has always been a priority. Through an interdisciplinary approach, DBR has assisted the industry in solving performance problems.

RESEARCH HIGHLIGHTS

The following pages of this report present the highlights of DBR's achievements over the past ten years. No attempt has been made to quantify the value of the research to the building industry. Rather, the approach in each case has been to state the problem, outline the nature of the research and show the application of the results.



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BUILDING PERFORMANCE

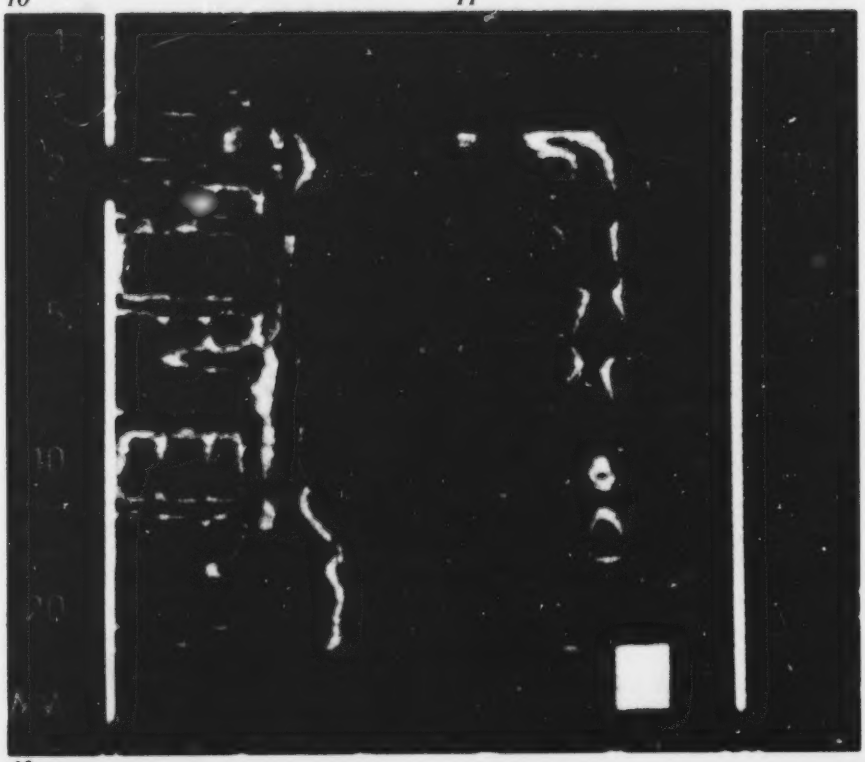
Building Envelope Problems

Too often we take buildings for granted and forget their most important function – to shelter. The building envelope – roofs, walls, windows and doors – must be an effective shield between the exterior and interior environments. It must prevent water leakage and condensation, resist air flow, and control heat loss. And it must do so continuously, at reasonable capital and operating costs.

Most building materials deteriorate when exposed to freezing and thawing, wetting and drying, sunlight, and chemical and biological attack. The rate of deterioration varies with the material, the severity of the climate, and the duration of exposure.

Other problems such as efflorescence and frost spalling of masonry may be caused by the movement of warm humid air through the envelope and its condensation on the outside surface. Energy efficiency may be poor because of excessive heat loss in cold weather. Air and vapour barriers are, therefore, important components of the building envelope.

Improving building performance requires co-operation between scientists and practitioners. It is not just a matter of studying the properties of materials in the laboratory; it is necessary to study their performance under service conditions.



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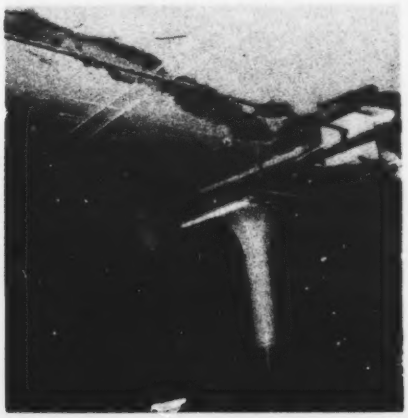

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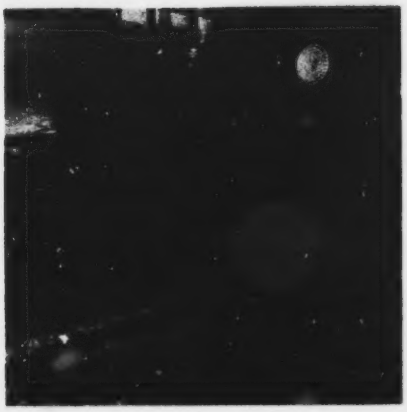

10.
Extensive research by DBR has improved the strength and durability of concrete.

11.
Wetting of exterior wall due to melting of frost accumulated inside the wall from condensation during cold weather.

12.
Thermogram of upper part of same building on a cold day showing variations in exterior surface temperature. Colours indicate a range of temperatures from relatively cold (blue and purple) to warm (white and black). Black indicates areas of high heat loss.

13.
Salt may be great for melting ice but it has disastrous effects on indoor parking garages.

14.
Close-up of concrete showing aggregate particles.

Toward More Durable Concrete

The deterioration of concrete used on the exterior of buildings and in parking garages, sidewalks and bridge decks is caused by cycles of wetting-and-drying and freezing-and-thawing. So serious is the problem in Canada that repairs will cost hundreds of millions of dollars.

During the last ten years DBR has studied the factors that affect the durability and performance of concrete. Investigations of the destructive mechanisms have resulted in:

- development of a theory of freezing in porous solids;
- new tests to assess the frost resistance of concrete, brick and stone;
- a new porous particle admixture that can replace conventional air-entraining agents in concrete;
- a CSA standard for paving blocks.

The disastrous effects of de-icing salts on the concrete reinforcement in indoor parking garages has been a subject of great concern. DBR, mostly through contracts, has studied the problem extensively and answered numerous inquiries.

The reinforcement of concrete products with mica flakes as a possible alternative to more expensive, and sometimes less durable, fibres was studied in cooperation with industry. Basic research has also increased understanding of the influence of the environment and material properties on the strength of cement.

The durability of concrete can be increased by impregnating it with various substances. DBR evaluated the performance of these substances and developed an accelerated method for assessing their durability.

On a related subject, a tough sulphur-asphalt mix for pothole repair on concrete and asphalt pavement has been developed, patented and licensed for manufacture.

Chemical Processes in Cementitious Materials

The performance of concrete is greatly influenced by the chemical nature of its "ingredients" and by the chemical processes it undergoes on exposure. Studies on portland cement, high alumina cement, cement admixtures, lime, magnesium and gypsum-based compounds have been undertaken to determine:

- the physical and chemical properties of their cement minerals;
- the causes of their deterioration, including kinetics of reactions and types of reaction products;
- their long-term performance. (This work has contributed to the development of accelerated test methods and the preparation of standards and codes of practice.)

Another important area of study concerns superplasticizers, a class of admixture used to lower the mix water requirements of concrete. A small amount of superplasticizer results in a more easily placed concrete but it loses workability within a few hours. DBR research has produced a retarder that retains workability for a longer period.

The use of cementitious materials in plasters has also been studied. It was found, for example, that some white-coat plasters show "bulging" or "popping" several years after application. Two test methods have been developed and incorporated into ASTM standards.

Alkali Reactivity in Concrete

A separate problem, the deterioration of concrete due to a reaction between certain minerals in aggregates and the alkalis in portland cement, came to DBR's attention in the 1950's in connection with aggregate from the Kingston area of Ontario. The problem recently reappeared in parts of Ontario and Quebec with rock previously thought to be unreactive. It is now considered that the reaction may be aggravated by recent

changes in the composition of cements and by the use of higher cement contents in modern high-strength concrete.

As a result of DBR studies, it is now possible to identify aggregates that cause expansion and cracking of concrete. Improvements have also been made in petrographic techniques for identifying potentially reactive aggregates. Three categories have been defined, based on mineralogical content and expansion characteristics of concrete prisms made with them:

- "classical" alkali-silica reactive aggregates characterized by early rapid expansion of concrete test prisms;
- "late expansive siliceous aggregates" — expansion begins in test prisms only after an initiation period of several months;
- "alkali-carbonate reactive aggregates" — immediate onset of expansion of concrete prisms; severe deterioration of concrete structures within five years.

It is of considerable economic significance to be able to identify potentially reactive aggregates and to develop methods for preventing damaging expansion. Results of this work and of studies to evaluate accelerated tests for these reactions will be incorporated into the proposed new Canadian standards for alkali reactivity in concrete.

Concrete Science, a book written by three DBR researchers and published in 1981, gives detailed information on the many aspects of concrete technology.

Durability of Plastics

When plastics are exposed to the elements, undesirable changes occur. Common are loss of gloss, strength and resilience, discoloration, crazing, cracking, impairment of mechanical properties, and reduced light transmission. Although solar radiation, moisture, low temperature and oxygen are the main causes of this deterioration, their relative effects on the various plastics are

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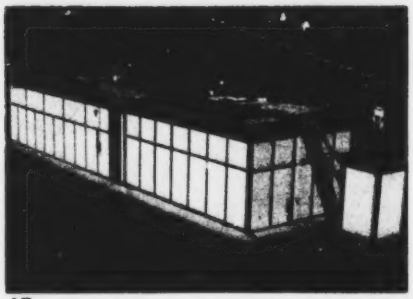

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15.
Plastics samples exposed to the elements in durability studies conducted by DBR.

16.
Clear finishes developed through DBR research preserve the beauty of wood.

17.
Roofing studies at the Prairie Regional Station in Saskatoon.

18.
Exposure testing of joint materials (sealants) on a DBR-designed exposure rack. The samples are subjected to different magnitudes of daily and seasonal temperature movements, depending on their location on the rack.

largely unknown. In an effort to understand these effects, different types of plastics were exposed at various angles for up to ten years. They were examined using the scanning electron microscope, and their tensile and impact strengths measured.

As a result, there is now a better understanding of the processes of deterioration induced by weathering. This knowledge coupled with DBR's accelerated test method for evaluating durability has improved standards governing quality of plastics.

Clear and Pigmented Coatings

Organic coatings, which include paints and clear finishes, are widely used and often represent large expenditures when applied by professionals. That performance problems are common and widespread is demonstrated by the many inquiries received by DBR.

Clear finishes for exterior use have been studied extensively at DBR because of the great interest in retaining the natural appearance of wood. Many coatings, including some recommended by foreign research laboratories, have been investigated, but none approached the performance of clear finishes complying with a CGSB standard that was based partly on DBR studies. In accelerated weathering tests, coatings developed at DBR have shown higher durability than other finishes. A Canadian company has signed a licence agreement and is testing the recommended formulation.

A more scientific evaluation of coatings is now possible as a result of these efforts. This has been of considerable benefit to industry, as well as standards committees of CGSB and ASTM.

Roofing Materials

The hundreds of roofing materials available today vary widely in properties and behaviour. The difficulty is that performance cannot be predicted. DBR, at the request of CMHC, is carrying out an extensive study of more than 100 new materials. They have been classified in six categories, each with its own characteristics that must be considered at the design stage of construction. DBR has assisted in developing test procedures to determine and measure pertinent properties, before and after accelerated exposure testing.

The performance of flat roofs is under study at the Prairie Regional Station, including methods of detecting moisture accumulation in the thermal insulation. Information has been obtained on the thermal resistance of various roof types and the effects of moisture on insulation values.

The results of these studies have provided the basis for CGSB standards. Educational seminars and advice on roofing have been given to the staff of several government departments and agencies. DBR maintains liaison with the Canadian Roofing Contractors Association on the development of new roofing materials.

Joint Materials

In many types of claddings and curtain walls, expansion and contraction due to temperature changes must be accommodated by the joints between building components. If the joints are filled with a "sealant" to prevent the passage of water, air and dust, the material used must be able to expand at low temperatures and contract at high temperatures. The demands on sealants are severe in Canada because of the very wide range of outdoor temperatures. In response to numerous inquiries related to the properties and durability of sealants, the Division started work on the development of a laboratory testing procedure that would predict their performance reliably.

The first step was to determine the extent and rate of movement of joints in exterior walls. Because sealants can accommodate slow dimensional changes better than rapid ones, establishing the rate of movement was as important as determining the amount. It was found that the tensile testing rates commonly used were about ten thousand times faster than would be imposed in service. As a result, slower tensile tests were developed.

To duplicate actual daily and seasonal outdoor temperature cycles, an exposure rack that responds to atmospheric temperature changes was developed. The movement at which a sealant starts to fail can be determined by observing similar specimens placed at positions of different movement on the rack. Because the rack is large and relatively expensive, a simple device was developed to subject specimens to intermittent movements while exposed to natural or laboratory conditions. This device has been useful to manufacturers in product development and to users in evaluating commercial products. When testing has been completed, the information will be communicated to standards-writing organizations.

Durability of Bricks and Design of Masonry Walls

When bricks get wet and freeze they may spall or crack and thus endanger the masonry cladding of a building. Tests now used to differentiate durable from non-durable bricks are not adequate; a fast and reliable test for predicting durability is required. This was the main objective of a fellowship sponsored at DBR by the Clay Brick Association of Canada. Extensive research in the laboratory and in brick plants showed that durability is related to pore structure, which can be controlled during manufacture.

Designers usually determine the compressive strength of a masonry wall design from the strength of an individual block or brick and the type of mortar used. Another method is to test small masonry specimens. Individual bricks, blocks, small masonry specimens (prisms) and larger masonry specimens (walls) were tested at DBR to check the reliability of both methods using Canadian materials. Axial strength and deformation were measured as well as variability. The tests on small masonry specimens gave a more accurate prediction of the behaviour of walls than tests

on single bricks or blocks, and it was found that workmanship can greatly influence strength. Results so far have provided input into CSA standards that are being reformulated to conform to the philosophy of limit states design. The tests are continuing on eccentrically loaded specimens.

Indoor Air Quality

Until about 1980, requirements for ventilation in buildings were based on controlling odours from cooking, smoking and people. But this did not guarantee clean air. With the trend to airtight buildings to save energy, the reduction in air movement between the inside and outside has led to higher concentrations of contaminants emanating not only from the occupants and their activities, but from building materials.

The Division has constructed a pair of test rooms where the ventilation rate can be controlled and the concentration of various contaminants measured. Contaminant concentrations in houses known to have low rates of natural ventilation are also being measured. This work was expanded in 1983 because of the increasing incidence of poor air quality attributable to energy conservation measures.

Some of DBR's techniques for measuring air infiltration rates and air contaminant concentrations are being used by consultants for routine investigations of air quality problems.

Better standards and better methods for controlling air quality will result from this research.

New Building Styles — Control of Fire and Smoke

Changes in architectural styles, construction methods, materials and building usage create new problems in fire safety and call for new approaches.

An architectural innovation of the last ten years is the atrium, a large multistorey public area in shopping centres and hotels. Many buildings with atriums were erected without regulation by building codes. DBR assisted the Associate Committee on the National Building Code in the development of measures to limit the movement of smoke in such buildings and to provide readily accessible refuge areas for occupants. Safety requirements were added to the NBC in 1977.

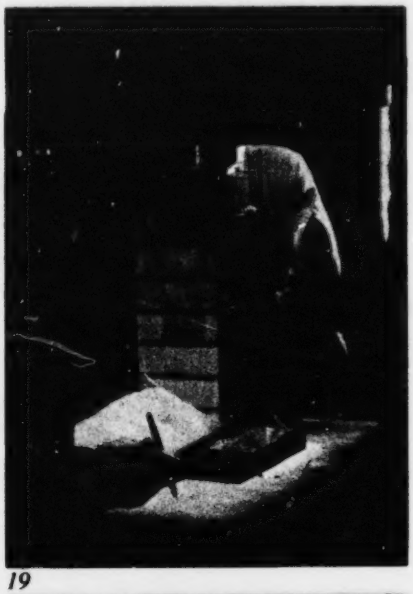
Fire protection problems created by new construction concepts are often too complex to be analyzed in conventional laboratories. DBR's Fire Research Field Station has facilities for studying a variety of fire problems under realistic conditions: smoke movement in high buildings; full-scale burn tests on simulated apartment and hospital suites, atriums, shopping malls and two-storey dwellings; how fire is influenced by fuel load, ventilation and wall linings; and the flammability of materials.

Noise Control in Buildings

It is relatively easy to measure sound transmission through a partition in the laboratory; it is not so easy to predict how a partition will perform when installed in a building. This is due to the many different sound transmission paths in a building and sometimes due to design and construction errors. How much sound insulation is needed in multifamily dwellings is a question that has not yet been resolved.

DBR often makes measurements in buildings to ascertain why partitions are not performing satisfactorily. Building occupants in various Canadian cities are being surveyed to determine their satisfaction with the sound insulation in their buildings. Results from a pilot survey show that good soundproofing can be achieved even in relatively inexpensive homes and that, as expected, occupant satisfaction increases as sound insulation increases.

Studies of the acoustical performance of walls and partitions, and occupant surveys both help designers and builders achieve economical design.



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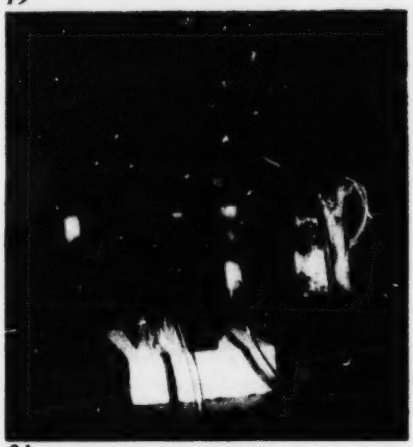

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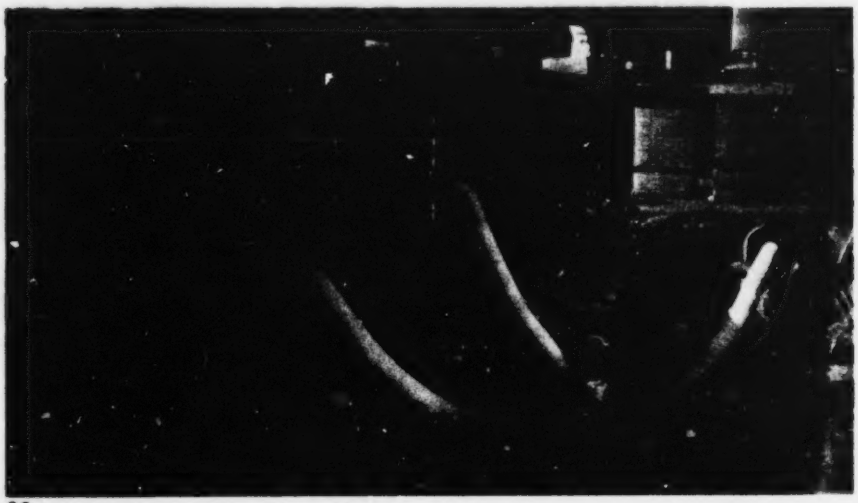
19.
Design values of the compressive strength of masonry are obtained through tests on masonry units (blocks and bricks) or small wall units.

20.
For realistic rain leakage tests on brick walls, air pressure differentials must be applied to simulate wind action on the windward side.

21.
Air quality monitoring is important in airtight buildings.

22.
The atrium is a popular feature in modern shopping centres.

23.
National Arts Centre Opera. DBR research aids in design improvements for acoustical excellence.



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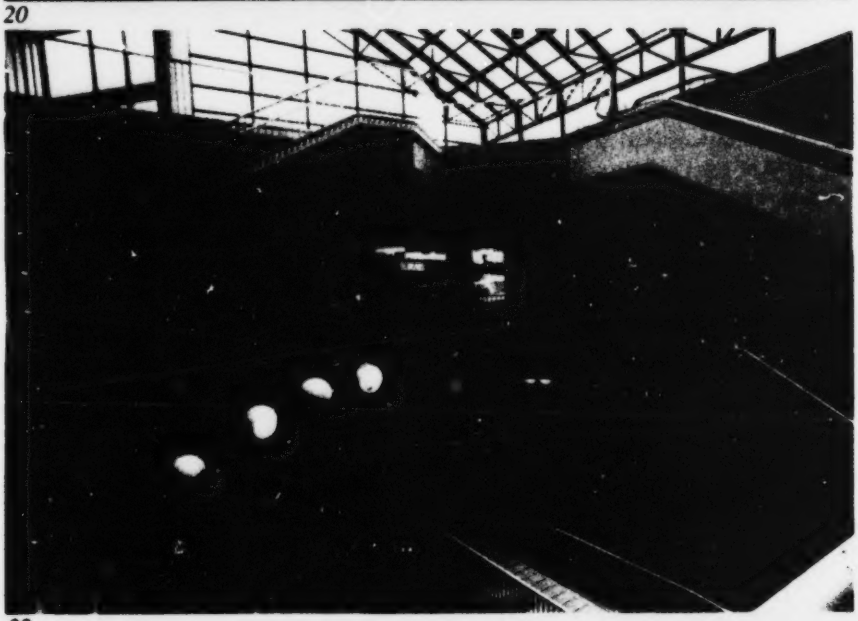

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Vibrations in Long-Span Floors

Recent changes in floor construction — longer spans, lighter components, and less damping — have caused annoying vibrations due to walking and rhythmic activities such as dancing. In response to inquiries, DBR investigated problem floors in buildings and test floors in the laboratory to identify the factors that affect vibration. Damping in the floor system was found to be the most important factor in vibrations from walking, whereas the natural frequency of the floor structure is the most important one affecting vibrations during rhythmic activities.

Guidelines and criteria based on these studies have been adopted for design practice. Criteria for walking vibrations are contained in CSA S16.1 (Steel Structures for Buildings — Limit States Design); criteria for rhythmic activities will be contained in the 1985 Supplement to the National Building Code. DBR has also recently proposed a simple damping device for existing floors to reduce annoying vibrations caused by walking.

Room Acoustics Design

Until recently, acoustical excellence in large meeting rooms, classrooms and auditoriums was sought by aiming for an optimum reverberation time. Research during the last 20 years, mainly in Europe, has shown that other, newer measures of room properties are a much better gauge of an audience's ability to hear speech or music. In response to requests from school boards, theatre companies and others, DBR has been investigating how these new measures can be estimated during the design phase and how well they work in predicting audience satisfaction. Computer model simulations are used in these studies, as well as in measurements of acoustical features of auditoriums such as the Opera of the National Arts Centre in Ottawa. This research should help avoid costly refitting to solve acoustical problems caused by inadequate design.

Building Economics

It is generally accepted that the design of a building should take into account the costs incurred over its lifetime and not simply the capital costs. Nevertheless, many design decisions ignore the future costs of operation and maintenance. Similarly, in a choice between demolition/rebuilding and rehabilitation, the cost consequences of the two should be weighed before a decision is made.

Building economics became part of the DBR research program in 1978. Early work evaluated techniques such as life-cycle costing and identified sources of economic data in Canada that could be applied to building. Studies of the economics of building rehabilitation have also begun; some work has been done on the economic impact of research and development, the effects of inflation on building costs, and research into building markets.

The importance of economics in building research has been clearly established but there is a shortage of data. New sources are being explored. The application of life-cycle costing to new and existing buildings is becoming more widespread across the country.

Safety, Security and Convenience

The design of a building should provide for the safety, security and convenience of occupants, including the disabled. Designers should also consider the effects of a building on the community, on the work environment, and on the health and satisfaction of users.

DBR studies on building use started in the early 1970's. Several were concerned with crowd movement in large public-assembly buildings where an emergency requiring evacuation can pose serious problems. Montreal's Olympic Stadium was the site of one such study. The Division advised on the design of stairs for Commonwealth Stadium in Edmonton and studied their use during the Commonwealth Games. A short film — ***The Stair Event*** — resulted from the project. The design of buildings for use by the physically disabled, particularly those in wheelchairs, was evaluated. Washroom requirements in stadiums were assessed, as were the mechanisms for the opening and closing of doors and windows and the manoeuverability of stretchers in hallways, stairs and exits.

It has been found that people behave remarkably well in fire emergencies. The mistakes they make are often due to insufficient knowledge of the situation causing the emergency.

THE ENERGY CRISIS

The federal government has set a goal of energy self-sufficiency by 1990. The means to achieve this are an increase in supplies and a decrease in consumption. With buildings accounting for more than one third of total energy consumption in Canada, opportunities exist to reduce consumption through conservation. The government set up the Canadian Home Insulation Program and the Canadian Oil Substitution Program, both of which require technical support. DBR is playing a leading role in cooperation with CMHC, Public Works Canada, and Energy, Mines and Resources Canada. Much of the research is being carried out under contracts with DBR.

Standards for Energy Conservation

In 1976 the federal government directed NRC to develop guidelines for energy conservation that could be used in the design of all buildings under federal jurisdiction. These guidelines were to be in the form of a model code that could be adopted by any province wishing to do so. Initially the intention was to produce a performance-type code — one that sets limits for energy consumption but leaves the designer free to choose how to meet those requirements. DBR established appropriate energy budgets for schools, offices and apartment buildings, but it was not possible to define a practical method for checking designs for compliance. Available calculation procedures gave widely varying results, depending on how the analyst described the building details, so that the guide-

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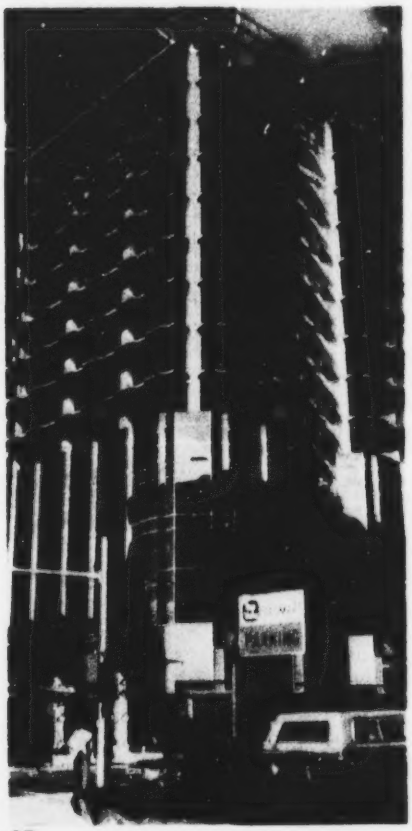

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lines were formulated in terms of component performance rather than an overall energy budget.

The proposed guidelines were based on ASHRAE Standard 90-75, with the requirements adjusted to account for the severe Canadian climate and based, as far as possible, on minimum life cycle costs. They were made available first for public review, following which a modified version was published in 1978 as "Measures for Energy Conservation in New Buildings."

This document has been used for all new buildings under federal jurisdiction as well as those of some provincial departments and agencies, and has had a significant influence on design practice throughout the country. An updated edition was issued in 1983.

Air Leakage

The principal function of a building enclosure is to inhibit the movement of air, moisture and heat between the outside and the inside. How well a wall or roof performs this function depends in part on the properties of the materials of construction and on how well they are assembled. DBR has various means for measuring, in the laboratory, the heat and moisture transfer characteristics of building materials and assemblies of materials. But the actual air leakage through walls and roofs can only be determined by measurements on buildings themselves as the rate depends greatly on the quality of construction.

The Division has extensively studied airtightness and the factors that affect it, on five types of buildings: tall office buildings, schools, retail stores, high-rise apartments and single-family homes. The results have been incorporated into computer programs for calculating the air infiltration component of building heating loads. They are enabling designers to predict air infiltration more precisely, to appreciate better its importance in heat loss, and to match the heating system to the load.

Energy Consumption in Houses

Designers need to know the effects of various design features on the energy required to heat a house. Calculation procedures are also needed to evaluate "retrofit" options for reducing the energy consumption of existing homes.

A number of computer programs have been developed to simulate the thermal performance of a house; one of these, ENCORE-CANADA, has been under continuing development at DBR since 1974. Because this type of program is too complicated and too costly to use for routine energy calculations, simplified methods have been prepared and incorporated into the DBR HOTCAN program for microcomputers.

HOTCAN is being used by CMHC, CSA and EMR to calculate the amount of energy needed to heat different types of houses and as a teaching tool at several colleges and universities in Canada. Some users have augmented the basic HOTCAN program with additional subroutines and data on construction costs to determine optimum amounts of insulation and the payback period for conservation features such as exhaust-air heat recuperators and triple-glazed windows.

Energy Consumption in Large Buildings

Owners or operators of apartment buildings, offices, schools and supermarkets can now compare the energy consumption of their building with that of similar structures, using data collected and published by DBR. The information has also been used to prepare energy consumption targets for these classes of buildings. In a supermarket study the energy used by refrigerated display counters, lights, fans, and heating and cooling equipment was also measured. This has provided not only a basis for mathematical modelling of such buildings but also guidance to supermarket owners on options for improved energy performance.

24.
DBR has studied the safety design aspects of public-assembly buildings and stadiums where emergency evacuations can pose serious problems.

25.
Insulation is a key to energy conservation.

26.
Fan pressurization test used to determine the air leakage characteristics of the exterior envelope of a large building.

27.
Replacing the wall system of an existing building to improve energy efficiency.

Basement Heat Loss

If a basement is not insulated, up to 25% of the heat provided to a house is lost through the basement walls and floors. The Division has developed a method to predict these losses so that better decisions can be made concerning measures to reduce the loss. On the other hand, if a basement wall is so well insulated that the ground adjoining the wall freezes and adheres to it (a process called adfreezing), damage to the structure can result. The two aspects of basement heat loss are being studied by the Division.

Experimental and theoretical studies have been carried out to develop and prove methods for predicting heat loss. Computer calculations have been made and the results verified by comparing them with basement measurements in several different soils and different regions. This has resulted in simplified calculation methods that have been incorporated into the HOTCAN program.

Adfreezing usually occurs after retrofitting of basement walls. It is not clear whether significant adfreezing is the norm or whether it arises only with some types of soil backfill and extreme climate conditions. During the winter of 1982-83, observations began on a full-scale test house whose basement walls were backfilled with clay prone to frost heave. The aim of the study is to determine the possible adverse effects of certain types and levels of insulation on the structural integrity of basement walls. Results from this study, to continue for several winters, will provide guidance to government programs to improve energy conservation in new and existing buildings.

Window Studies

Heat losses through windows, disregarding solar heat gains, are rather large compared with those through a well insulated wall. Calculation of window heat loss is difficult because much of the thermal resistance is provided by the inside and outside surface film resistances, which depend mainly on air ve-

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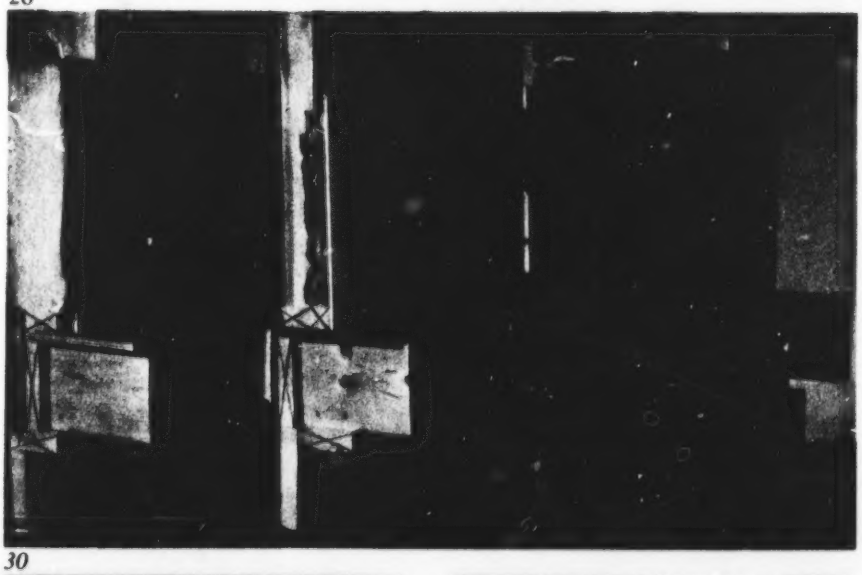

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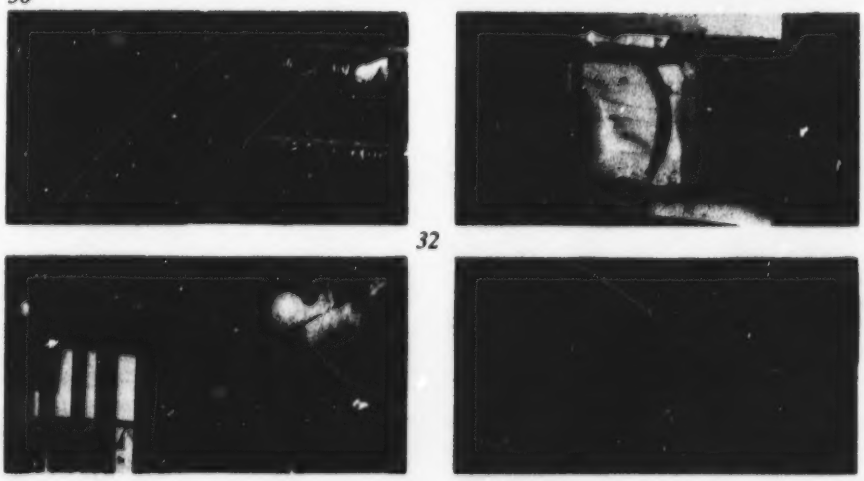

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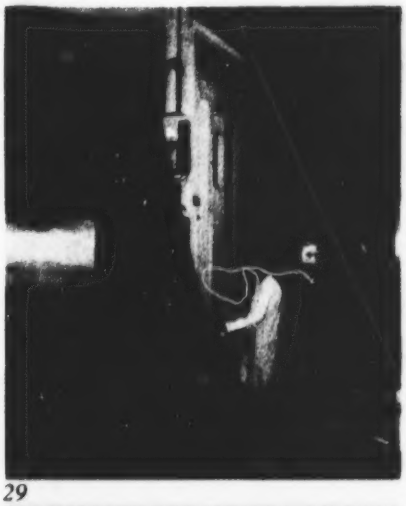

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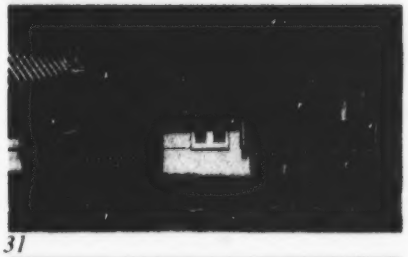

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28.
A large building in western Canada required 50% relative humidity on two floors to accommodate computer equipment. DBR assisted the consultants in upgrading the windows that had been selected for the rest of the building.

29.
DBR's large test facility for determining the heat loss of a complete wall assembly.

30.
Models used to show different ways of increasing the thermal resistance of wood frame walls.

31.
A low-energy house under construction on the Prairies.

32.
Some of the features of low-energy houses:
top left: high levels of insulation and a properly installed air-vapour barrier.
top right: careful sealing around electrical connections.
bottom left: light fixtures on walls instead of ceilings to reduce air leakage.
bottom right: meticulous caulking of all joints.

locities over the window surface. The frame and the geometry of the window also have a large effect on the total heat loss and complicate estimates based on the glazed portion only. Knowledge of these losses and the factors that control them is important for energy calculations and for assessing performance.

DBR has carried out research and testing on windows for several years to obtain this information and to develop performance criteria and testing methods for the technical support of the manufacturing industry in Canada. Hundreds of double- and triple-glazing units have been tested for manufacturers. The results are used by CMHC to verify that products meet Canadian standards for sealed window units. DBR works closely with the Insulated Glass Manufacturers Association of Canada on the improvement of windows.

Heat Loss through Walls and Windows

Designers need to know the thermal resistance of walls and windows for heat loss calculations. DBR has constructed a large testing apparatus to satisfy this need. It consists of a warm chamber, open on one side, with which one can simulate indoor conditions, and a second similar chamber with which one can impose outdoor conditions with temperatures down to −45°C. The wall or window unit to be tested is placed between the two.

Tests carried out in these facilities help industry identify shortcomings of proposed designs and the modifications necessary to make a unit more thermally effective. Measured values of thermal resistance are compared with calculated values based on the thermal conductivity of the materials used in the unit and their arrangement and thickness. Factors that determine this difference, such as density and thickness of insulation, are being studied so as to develop design methods that will not require large-scale, expensive tests to confirm behaviour.

Prior to 1981 only DBR had facilities for testing large wall and window units under the wide range of climatic conditions that occurs in Canada. The Division assisted a commercial testing laboratory to design and construct a similar apparatus and arranged for a series of wall sample tests both there and at NRC for purposes of comparison and calibration. That company now does commercial testing for Canadian manufacturers and DBR continues its research and development of test methods. This will eventually lead to upgrading of the standard test procedures issued by CGSB, CSA and ASTM.

Low-Energy Houses

The development of technology for low-energy houses requires the cooperation of owners who are willing to spend extra money on energy conservation, builders who have to learn and apply new techniques, governments who provide various forms of encouragement, and researchers who provide guidance.

DBR staff in Ottawa and Saskatoon have been active in research on the design and construction of low-energy houses. The Prairie Regional Station has done extensive work with builders who wished to build such homes and with individuals who were constructing their own. Several hundred homes, incorporating many different features, have been built. DBR has published a number of reports on the improved techniques that have been developed, as well as several versions of the HOTCAN computer program for estimating heat balance in houses.

HUDAC Research Houses

In 1977 the Division, in cooperation with the Housing and Urban Development Association of Canada, undertook to carry out field trials of some energy conservation measures. Four two-storey detached houses were built by HUDAC in Orleans, just east of Ottawa, and instrumented by DBR. The objectives of the project were to:

– compare the annual heating cost for a house built to the standard of the

"1978 Energy Measures" with that for a similar house built to the previous CMHC requirements;

- compare the actual energy used to heat these houses with that predicted by various computer programs;

- compare the actual heating cost of three similar houses, one using an active solar heating system with electric furnace back-up, one using an air-to-air heat pump, also with electric back-up, and a third with a conventional forced-air electric furnace only;

- measure the rate of heat flow through the walls both above and below grade to confirm that performance in a house is the same as would be predicted from laboratory tests.

The results showed that the upgraded house had over 20% less annual heat loss than the similar house built to the 1975 standard. The results compared quite well with calculated values of heat loss through the above-grade portions of the building, but the heat loss from the basement walls and floor was greater than the calculated values.

The house with an air-to-air heat pump required much less purchased energy than the equivalent house with a conventional electric furnace. The solar heating system was less effective than the heat pump, and much more expensive to purchase and install.

The houses were also used to:

- check the seasonal efficiency of conventional and high-efficiency gas furnaces under normal operating conditions rather than artificial test conditions;

- obtain air infiltration values and an equivalent air leakage area for a house to determine whether it is possible to deduce the average rate of infiltration from the measured air leakage area;

- to check the effectiveness of various mechanical ventilation systems in controlling the build-up of water vapour and pollutants in airtight houses.

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33.
DBR carried out extensive energy conservation studies on these four single-family homes built by HUDAC east of Ottawa.

34.
Shrinkage of urea formaldehyde foam insulation (UFFI) in a wood-frame wall.

35.
Solar panels atop a DBR laboratory building.

36.
Test huts used by DBR for the study of passive solar heating.

These test houses have been an important adjunct to laboratory testing facilities and effective in providing that important link between DBR and builders.

Urea Formaldehyde Foam Insulation

Urea formaldehyde foam insulation (UFFI) came into use in Canada in the last 15 to 20 years mainly for upgrading the walls of older houses. A foamed-in-place insulation, UFFI had been used to a moderate extent in earlier years but became much more popular after 1977 as a result of consumer demand and active marketing by the industry. Reports of medical problems attributed to gaseous emissions from the foam resulted in a ban on the product in December 1980 under the federal Hazardous Products Act. There were also reports of structural deterioration in houses.

Shrinkage had been quickly identified by DBR as detrimental to the long-term effectiveness of UFFI as a thermal insulation material. Since the ban, the Division has devoted considerable effort to UFFI studies. Much of the work was done through research contracts with some 50 researchers in laboratories and universities across Canada. The major concerns have been: the determination of why UFFI affects occupants, the development of simple and inexpensive methods for measuring the concentration of emissions, the establishment of ways and means of reducing concentrations to acceptable levels, and the development of satisfactory methods to neutralize or remove UFFI when necessary.

The properties of UFFI in a particular house, the sensitivity of the occupants, and the building characteristics all influence the situation. As no two houses, occupants or UFFI installations are likely to be the same, the problem is a most complicated one.

The Division has issued two Building Practice Notes (Nos. 19 and 23) on UFFI. No. 19 is a general overview of the characteristics of the foam and potential problems when it is installed in a building. No. 23, more detailed, guides consumers and contractors in solving problems. Further research on UFFI and how to get rid of its disturbing effects will be a major research activity for DBR until at least 1986.

Active Solar Heating

Solar energy can provide heat for a building in several ways. If the sun simply shines through windows or on the exterior of the building, thereby reducing the heat loss, this is referred to as passive solar heating. Active solar heating is the use of fans or pumps to circulate a fluid through a solar collector (where it picks up heat) and thence to the building.

DBR research on active solar began in 1975 with a feasibility study on solar's potential. This was followed by the installation and monitoring of a number of residential solar heating systems across the country. A test facility was constructed at the Ottawa laboratories to support the development of standards for solar heating components.

As funding increased, the Solar Energy Project was created by NRC to oversee the solar program and manage contracts on system trials, design methods and product development. The development of test methods and standards for solar collectors remained with the Division, however, as did responsibility for the calibration of commercial testing facilities and the support of various standards bodies such as CSA, ASHRAE, ASTM, IEA and ISO.

NRC has recently supported the development of commercial test facilities in Ontario, Quebec and British Columbia. DBR provided guidance on the design of these facilities and will act as a calibration source to ensure consistent test results nationally and internationally.

In a separate study DBR is examining the durability of solar collectors as the future for active solar heating depends very much on this factor. Although a 20-year life is commonly assumed in estimating the cost of solar heating, little is known about the actual life expectancy of collectors under service conditions. A rapid method for estimating long-term durability is needed. The reactions of collector materials to various weathering factors, such as ultraviolet radiation, temperature extremes, and moisture cycles are being determined and the results will be made available for the development of standards.

Passive Solar Heating

Passive solar heating systems have gained popularity in recent years but it has been difficult to predict their performance. The objectives of the passive solar heating program are to assess the potential for this approach in Canada, to provide the building industry with methods for designing passively heated buildings, and to compare the relative merits of the various passive solar methods with each other and with more conventional energy conservation techniques.

Tests were begun in 1980 on three full-size passively heated test huts. The purpose was to determine the thermal performance of houses with different amounts of heat storage capacity and thus to verify a computer simulation program used to develop design guidelines for passive solar heating systems.

A simple method for predicting the heating energy requirements of direct-gain passive solar houses has been developed. It is applicable to all types of houses, from high-mass direct-gain types to lightweight wood-frame structures. The method has been incorporated into a graphical procedure that can be used easily during the design process to determine the best combination of south window area and thermal storage capacity and thereby minimize space heating costs.

Heat Pumps

A heat pump is a refrigeration machine that takes in energy at a low temperature from one location (e.g., outdoors) and delivers it at a higher temperature to

another location (e.g., indoors). The amount of heat delivered is the sum of heat removed from the source and an amount equal to the power used to drive the machine.

A heat pump is especially attractive if both the cooling effect and heating effect can be utilized. This is often possible in large office buildings where the core area requires cooling while some perimeter areas require heating. Heat pumps used for heating and cooling typically produce about 2 kW of cooling and 3 kW of heating for each kilowatt of power consumed. Thus, if electricity is used to drive the heat pump rather than for direct heating, the "effective efficiency" is increased by a factor of about three.

DBR has investigated the economics, seasonal performance and reliability of residential heat pumps, the performance of systems combining a heat pump and an oil or gas furnace, the feasibility of heat sources such as groundwater, the municipal water supply, and exhaust air from houses. Much of this work has been done through contracts.

Research results have been applied in the development and application of heat pump systems. Conclusions from the DBR study of the economics of air-source systems were used to establish the size of heat pumps eligible for grants under the Canada Oil Substitution Program.

Lighting Energy Conservation

Lighting consumes a sizeable amount of energy in commercial and institutional buildings. There is a widespread view that much of this energy could be saved without seriously affecting productivity in the workplace. DBR has been identifying practical ways of achieving this.

The first step, of course, is to turn lights off when not needed. The second is to arrange equipment and furniture so that the lighting is adequate for the visual tasks to be performed. The research is seeking to determine the relationship between visual performance and various properties of the lighting system with a view to establishing national criteria for specifying lighting system performance. This work will influence lighting design through changes in the recommendations of the Illuminating Engineering Society of North America.

The Division has evaluated the use of automatic controls to turn off lights when a room is unoccupied or when there is enough natural light. Savings realized by increasing the number of local switches and using posters and labels to remind people to switch off when they leave a room have also been assessed; these approaches are of interest to the electrical utilities, and the Canadian Electrical Association (CEA) is sponsoring a research fellowship at DBR to study them.

DBR has advised various institutions concerned with lighting and vision and has been working with national and international committees on lighting requirements and visual performance.

Heat Storage

On a hot August day, memories of winter might trigger thoughts about storing summer heat for the next winter. This is interesting not only in connection with the storage of solar energy but also in regard to the storage and re-use of industrial waste heat. DBR has been studying the problem of ground thermal storage and how to recover this heat economically when needed. One aspect involves comparing the performance of normal, relatively expensive, rigid storage tanks with that of underground containers with flexible plastic walls. This has evolved into a system of small holes drilled in the ground and lined with flexible membrane. Heat is transferred through the liners, and the ground itself acts as the storage medium. These vertical heat exchangers in combination with a heat pump may be the answer to a summer wish.

Another aspect of thermal storage, albeit of a short-term nature, is the potential of the building mass for reducing peak

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37.
Insulated tank being lowered into a drilled hole (clay) for studies of ground thermal storage.

38.
Measurements of snow loads help in refining design load information in the National Building Code.

39.
This scale model of downtown Toronto (including instrumented model of Commerce Court) was built for wind tunnel tests. The purpose was to compare results with those of full-scale measurements on Commerce Court.

cooling loads in summer and peak heating loads in winter. This potential can be realized by combining heavy interior construction with large window areas facing south. To obtain better insight into this complex problem, DBR did several experimental and theoretical studies. The results were incorporated into ASHRAE'S Design Handbook. The method of considering internal mass has also been incorporated in several computer programs, including HOTCAN, for predicting the energy performance of buildings.

MATTERS OF SAFETY

A fundamental requirement of a building is that it be safe for its occupants. While it is impossible to prevent all accidents, the probability can be reduced by proper design. Because most design safety features cost money, questions arise: what degree of safety should one strive for?; what probability of an extreme event occurring is acceptable? These are among the most important questions facing building code committees, who are expected to limit the possibility of structural collapse and fire and to minimize risk to health. It is not surprising then that research projects frequently originate from suggestions of code committees.

Limit States Design

All structures have two basic requirements: safety from collapse and satisfactory performance. Designers must ensure that these criteria are met. Ways of achieving this have evolved from traditional building rules through to allowable stress design, to today's method, called limit states design. "Limit states" is the term given to modes of failure in a building, ranging from annoying vibrations to collapse. Laboratory and field studies have been instrumental in limit states design's being accepted for use in the National Building Code.

Its advantages are: it ensures the economical use of materials and a wide range of applications by providing consistent safety and serviceability; it provides a checklist of the basic structural requirements for which design calculations may be required; and it provides a basic calculation tool for designing and evaluating civil engineering structures as well as a means for unifying structural codes and standards.

Limit states design was first adopted for steel structures in the 1975 edition of the National Building Code and is gradually being adopted for other structural design codes and standards. Its adoption for steel structures resulted in an overall annual saving of 5% in materials. Based on limit states concepts, DBR has long advocated that the material resistance factor for concrete structures be included in codes; this suggestion has recently been adopted and should result in an overall saving of 5% in the amount of structural reinforcement required.

Snow Loads on Roofs

Studies of snow loads on roofs began in 1956 to resolve a conflict between the assumed design snow loads and the (low) strength of house roofs measured in the laboratory. After 10 years of observations (needed because of the variability of the winter climate), design loads were lowered, resulting in annual savings of millions of dollars. Now research is largely in response to requests from committees of the National Building Code.

For example, safety concerns led to research on unsymmetrical snow loads on arch roofs. This work, begun in 1975, has already reduced the incidence of failures as a result of the inclusion of new design loads in the Commentary. Other snow studies include determining the effect of surface roughness on snow accumulation on a sloping roof before it slides off. The loads on nine experimental roofs, sheltered from sun and wind, with smooth and rough surfaces and slopes between 0° and 60° were recorded weekly. On the basis of these studies an extra load reduction related to slope has been proposed for slippery roofs in the 1985 edition of the NBC. Surveys of uniform and drift load on one- and two-level flat roofs, the drifting of snow around solar collectors, and snow loads in the mountains and valleys of British Columbia were also conducted.

The results of these surveys have economic and safety implications for the 18 million square metres of roof built annually in Canada.

Effects of Wind on Buildings

Reliable estimates of wind loads are needed for the safe and economical design of structures and claddings. Twenty years ago, little was known about wind effects or how to model them in a wind tunnel. DBR, at the request of the Associate Committee on the National Building Code, started monitoring wind pressures on buildings.

Methods of measurement improved, and in seven years the Division had a large collection of detailed field data mostly from Commerce Court West, a 57-storey office tower in Toronto. Included in these were measurements of horizontal acceleration and displacement at the top of the building during strong wind storms. These measurements and those on a model in a wind tunnel showed that a good part of the motion was due to rotation about a vertical axis not at the centre of the building. This torsion component added about 40% to the accelerations at one end, compared with those at the other. The measurements signalled the importance of considering torsion in design and the value of model studies in predicting motion. Calculation methods used in the NBC were confirmed.

Wind pressures on individual cladding panels are more difficult to estimate than the averaged pressure needed in designing a structure. Design of glass cladding is further complicated by dynamic fatigue in glass, i.e., the longer a panel is loaded, the lower will be the pressure at which it fails. Current design practice uses the peak pressure, but its duration is ignored. The pressure measurements on Commerce Court provided information on the actual loading

on claddings. Experiments were needed, however, to clarify the role of dynamic fatigue in large glass panels.

A test apparatus to simulate wind gusts on panels was built for DBR by the Ontario Research Foundation. Two hundred samples of 6-mm thick glass were tested to failure at various loading rates in a two-year program jointly funded by DBR and three major glass manufacturers. The ORF results together with DBR cladding pressure measurements suggest that the current Canadian practice of using peak gusts is conservative, and in some cases savings of up to 25% may be achieved.

Design of Buildings for Fire Safety

A fire-safe building could be defined as one in which the probability of fire is low, and if it should occur the probability is high that all occupants will survive and damage will be confined to the immediate fire area. The most important fire safety requirements are included in building codes, which regulate design and construction materials, and in fire codes which regulate the contents of buildings. There is a need for better understanding of fire-related problems and the knowledge to solve them.

Fire safety depends on many factors. Some of them are related to building design, such as layout and dimensions, the selection of materials, and the use of safety devices and facilities. Others are related to the occupants' behaviour patterns: their awareness of the danger of fire and the way they arrange furniture and equipment in building compartments.

To help designers make objective decisions, a technique for assessing the fire risk involved in the use of building products and furnishings has been suggested. This technique, now being considered for inclusion in an ASTM standard, makes it possible to characterize, by a single "potential-for-harm" number, the overall peril in using a product. The goal of the project is to develop the knowledge base and methodologies required by designers to ensure that their buildings are safe from fire and conform to the requirements of building codes.

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40.
A number of serious fires in high-rise buildings in recent years has heightened interest in smoke control and fire safety.

41.
Fire test on sloping roof panel.

Smoke in High-rise Buildings

The time required to evacuate a high-rise building increases rapidly with building height, and can exceed half an hour when there are 20 or more stories. In a fire, smoke will migrate to the upper floors through the stair and elevator shafts unless there is a way to control it. Buildings should be equipped with smoke control devices to keep stair shafts clear until all the occupants have escaped.

Smoke follows the upward movement of air caused by the normal temperature difference between the inside and the outside (called stack effect), wind action, building air-handling systems, and certain effects of the fire itself. These forces cause pressure differences across building elements such as partitions and doors. Smoke control is achieved by fans which create a higher pressure in all parts of the escape routes and refuge areas than that in the rest of the building.

Mathematical models and field observations have been used to study smoke movement and to devise control methods. The models include the effects of high temperatures caused by fires, but so far it has not been possible to validate predicted behaviour by observations under real fire conditions. It is particularly valuable that such conditions can now be simulated at the DBR Fire Research Field Station.

This work has provided the basis for standards and for the smoke control measures that have been incorporated into the National Building Code.

Fire Resistance of Building Elements

Fire-resistant compartmentation has long been the core of fire protection in buildings. According to this concept, if the compartment boundaries have sufficient fire resistance, a fire will be confined to the area of origin. The fire resistance of various building elements such as beams, columns and walls is usually determined by standard tests. As such tests are time consuming and expensive, methods are required by which fire resistance can be calculated.

Experimental and theoretical studies are providing the basis by which one can calculate the fire resistance of steel beams and columns, concrete columns and slabs, and timber beams. In order to make these calculations, one must know the properties of the materials used in the building elements. To this end, DBR has developed information on the thermal and mechanical properties of many building materials at elevated temperatures. The specific heat, thermal conductivity, and dilatometric and thermogravimetric characteristics of 31 materials have been published; information on other materials will be published as it becomes available.

A three-phase study of reinforced concrete columns has been undertaken to update the fire resistance information in the National Building Code. Conducted in cooperation with the Portland Cement Association, its main objective is to develop design methods for a wide range of applications.

Tubular steel columns filled with concrete offer several advantages over conventional steel columns with regard to strength, cost and space utilization. Further advantages are gained by using high-strength concrete. Mathematical models have been developed to predict the fire performance of such columns; the Canadian steel industry provided materials and technical support.

A study of the fire resistance of timber beams and columns was undertaken in cooperation with North American wood interests.

Information resulting from work on fire resistance has been incorporated into the National Building Code and into design guides and manuals.

The Phases of Fire

A fire consists of various phases: ignition, initial flame spread, preflashover growth, full development, and inter-compartmental spread. The spread of smoke may be associated with any of them. The development of fire safety measures for buildings depends on a proper understanding of these phases.

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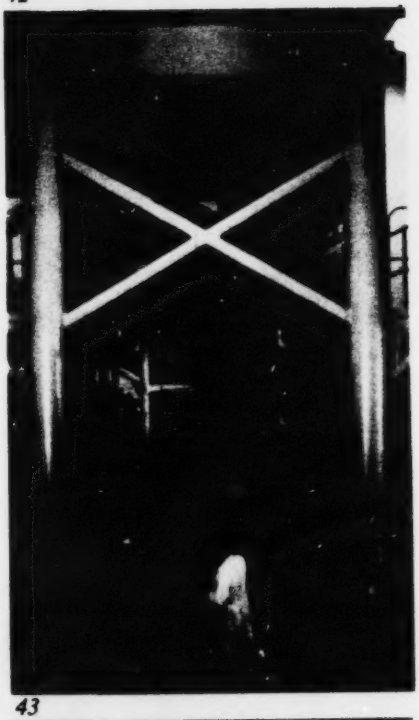

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42.
Full-scale room burn experiment at the Fire Research Field Station.

43.
DBR column-test furnace for full-scale fire tests on reinforced concrete columns and concrete-filled tubular steel columns, under load.

The first defence against fire is the prevention or delay of ignition. Ignition processes and accompanying physical and chemical phenomena have been studied by the Division. Studies of flame spread have formed the basis for performance tests that reproduce more accurately the actual behaviour of the surface of materials when exposed to fire.

Flames advance to other objects by convection and radiation. DBR is part of an international effort to learn more about fire development during the preflashover period.

The mathematical model developed for quantifying the potential of fires to spread from one compartment to another has been tested in a series of full-scale room-burn experiments and found to be reliable. It enables one to assess the fire resistance requirements for compartment boundaries.

Toxicity of Fire Gases

Canada and the United States lead the world in fire deaths per capita. Most fatalities are due to inhalation of smoke and gases rather than burns. The most common toxic components of fire gases are carbon monoxide, aldehydes from hydrocarbon polymers and cellulosic materials, hydrochloric acid from polyvinyl chloride and other chlorine-containing polymers, hydrogen cyanide and oxides of nitrogen from polymers containing nitrogen.

DBR has long been engaged in the chemical analysis of fire gases. An ongoing concern has been the overall toxicity of the gases generated by different combustible materials. The concept of a 'toxicity index' was developed by DBR to rank the toxic potential of materials on the basis of the chemical analysis of the gases released on burning. To validate this concept a study was initiated with Japan several years ago, combining Canadian expertise in chemical analysis and Japanese expertise in animal experiments. The United States is now part of the study.

The toxicity index has been adopted by the U.K. Ministry of Defence (Naval Engineering) for procurement purposes. Information developed on the toxicity of the fire gases produced by several plastics is widely used in the industry and in the fire research community.

Avalanche Engineering

In an average year about 4000 snow avalanches occur near roads, railways, powerlines and ski resorts in Western Canada. Thousands more occur in remote areas where they may still endanger skiers, mountain climbers and people riding in snow vehicles. Between 1972 and 1982 the annual toll from avalanches in Canada was seven deaths and $600 000 in property damage.

DBR staff carry out studies of avalanches and protective measures from their field station at Revelstoke, B.C. The information collected aids in the design of ski-lift towers, bridges, snow sheds and protective earth works, and in the location of roads and buildings.

The safety of skiers and motorists often necessitates travel restrictions during dangerous periods. Predicting these periods requires knowledge of snow, avalanches and weather as well as skills in interpreting data. In cooperation with the B.C. Institute of Technology in Vancouver, DBR organized a training program for persons concerned with avalanche safety for roads, parks, recreational areas and industrial sites. The first course in 1971 was attended by 20 persons. In 1982 the attendance was ten times that number.

DBR staff helped establish the Canadian Avalanche Association, an organization devoted to the promotion of safety in avalanche country.

Earthquake Engineering

Historical records and earth tremors within memory attest to the potential for destructive earthquakes in Canada, particularly on the west coast and along the lower St. Lawrence River. DBR assists

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44.
Seismic Zoning Map shows probability of damaging earthquakes:
Zone 0 – negligible; Zone 1 – small;
Zone 2 – moderate;
Zone 3 – greatest.

45.
Avalanches in British Columbia have a lot of get-up-and-go.

in a number of ways to protect buildings from extensive damage or collapse during major earthquakes.

The Division operates a network of strong-motion seismographs in Eastern Canada. These instruments are triggered by strong earthquakes and automatically record the ground motions. The records are used to characterize the earthquakes so that they can be related to the observed effects on structures and people. They also provide a basis for seismic risk evaluation and improvements in the National Building Code. Following the New Brunswick earthquake of January 1982, for example, a number of background papers were prepared to assist the code committees.

Although building designs must be adequate to prevent major loss of life in an earthquake, they should also be as economical as possible. Continuing research helps ensure both goals are met.

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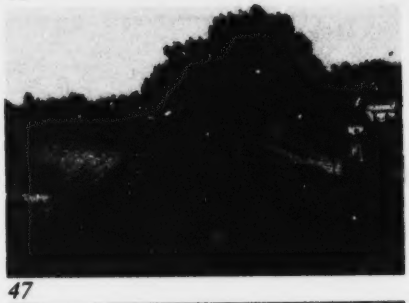

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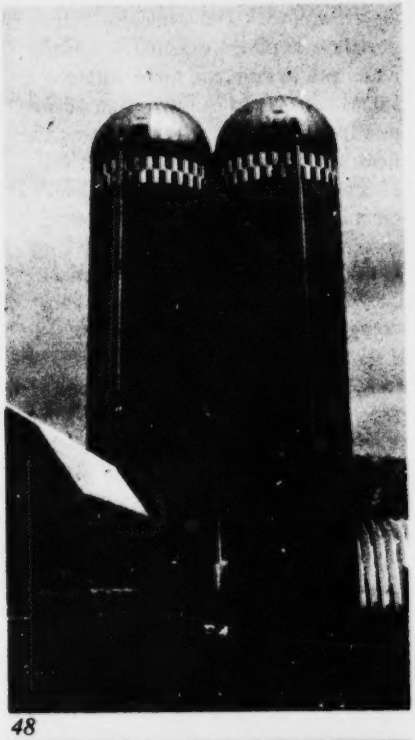

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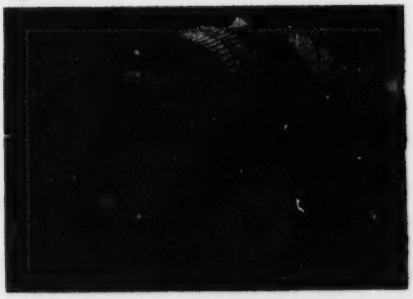

46.
Leda clay is a very sensitive marine clay found in the Ottawa and St. Lawrence River lowlands. Groundwater is known to have an important influence on stability and many slope failures occur when the groundwater table is high during spring run-off. DBR instrumented a number of natural slopes near Ottawa to observe seasonal fluctuations and to define the critical groundwater condition.

47.
Raising the embankment height on weak clay in a study of "stage construction". The first stage was placed a number of years prior to the final stage to allow the clay to gain strength as it consolidated.

48.
The Leaning Towers of Feed. Tall silos built on soft clays may settle and tilt if the foundation design does not reflect the soil condition. Collapse occurs in some cases.

FIELD AND SPECIAL STUDIES

Studies on Soft Clays

Some areas of Canada, notably the St. Lawrence and Ottawa valleys, have deposits of soft, sensitive clays. These soils have low strength and high compressibility and impose limitations on foundations for buildings and other structures. Particular attention in recent DBR studies has been paid to the behaviour of earthfills placed on soft clays, landslides, downdrag loads on piles, the design of foundations for tower silos, and sampling and testing techniques.

Earthfills. It is necessary to know how soft clays will behave under heavy loads in order to design adequate foundations. A project was started in 1967 when a 2.4-m test earthfill was placed on soft clay at a site near Ottawa. The fill was constructed to the maximum height that the soil could support at the time and the fill and subsoil were instrumented.

Measurements over the next seven years provided valuable information on the rate and amount of settlement in the subsoil and were used to verify design methods. In 1982 it was possible to add a second stage, increasing the height of the fill to 4.6 m and the load by 85%. The purpose of this second stage was to confirm the theory that a soft clay gains strength as it compresses, and to verify the design of foundations on compressible clays as a means of evaluating different design procedures.

Pile foundations. Piles installed through soft clays that compress under the weight of new surface loads are sometimes subjected to a substantial "downdrag" load that increases with time and reduces the load-carrying capacity of the piles. Full-scale pile load tests have been carried out in cooperation with the New Brunswick Department of Transportation to measure actual downdrag loads and to compare them with the forces considered in the design of the pile foundations. It was found that such loads can be determined from in situ effective stresses and from the coefficient of friction between soil and piles.

Tower silos. As agriculture becomes more intensive, larger tower silos for storage of feed have been constructed. If these larger and heavier silos are built on soft clays, failure can, and does, occur. In cooperation with universities, provincial agencies and silo contractors, a number of failures have been investigated in Ontario and Quebec. The results will be incorporated into a foundation design manual for the industry.

Testing methods. To carry out accurate design calculations in geotechnical engineering, very good (undisturbed) soil samples must be obtained or reliable in situ techniques employed for the measurement of strength and compressibility. DBR has been active in the development of specialized sampling equipment and testing methods; a recent advance is the development of computer techniques for the control and interpretation of testing. Such techniques are shared where possible with other agencies where full-scale construction is in

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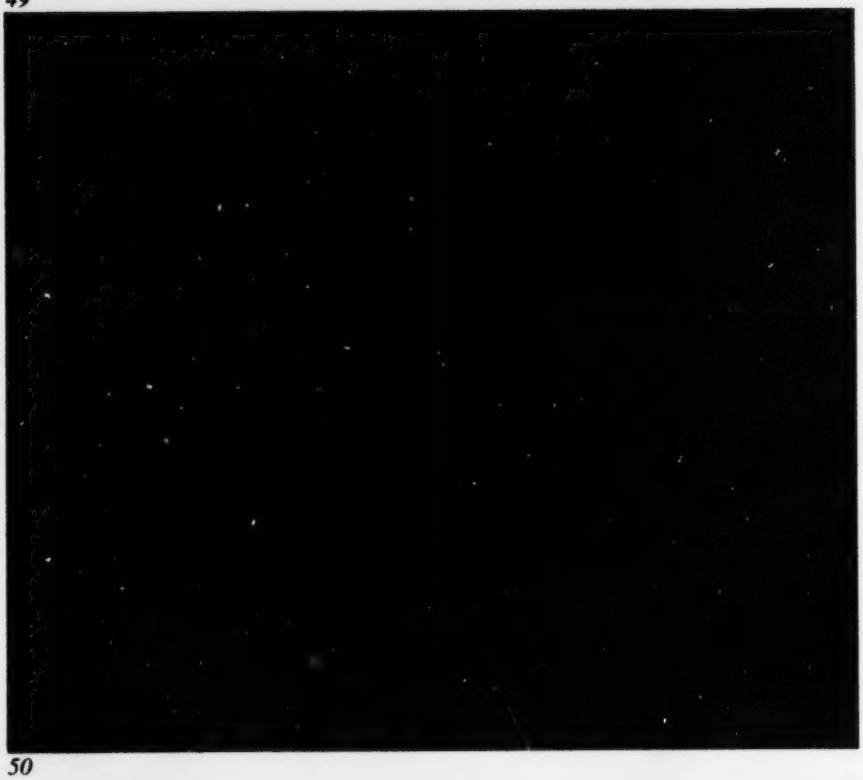

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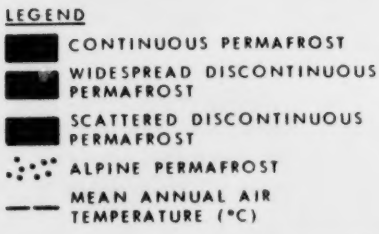

49.
Altered pyritic shale under a building caused by biogeochemical weathering.

50.
The permafrost region of Canada.

progress. The Division helps these agencies monitor the behaviour of structures after their completion to verify design predictions obtained through laboratory or in situ testing. The latest equipment devised by the Division is a triaxial apparatus to study the dynamic behaviour of soft clays under vibratory or earthquake loading.

Expansive Shales

Problems have occurred with some buildings founded on certain types of shale. Concrete floor slabs have broken up, mechanical equipment in basements has been put out of alignment, and interior partitions have been wracked. The cause is expansion of the shale triggered by pyrite contained in it. Pyrite is an iron sulphide mineral which, when exposed to air, causes acid-producing bacteria to induce chemical changes that cause the shale to expand. It is not always possible to avoid construction on such shales and in many cases buildings were erected before the problem was understood. Control methods such as excluding air or removing the reaction products have been only partially successful. Restraining expansion in vital areas shows more promise, and in a recent experiment plates anchored to rock at depth have resisted all movement. It is too early to say whether this method will be suitable for general application. Sensitive equipment, however, could possibly be protected in this way.

Permafrost

Permafrost (perennially frozen ground) underlies more than half the land area of Canada. If the performance of structures in permafrost areas is to be successful, the nature of permafrost and its distribution must be known and appropriate design and construction methods used to prevent the ground from thawing.

DBR has carried out extensive field studies to determine where and how permafrost occurs. Permafrost areas have been mapped, ground temperatures measured, and climatic and terrain factors evaluated at many sites in northern Canada. As an aid to construction, field and laboratory investigations have been carried out to determine the properties and strength and deformation behaviour of frozen soils. Much emphasis is being placed on standardizing testing procedures in the laboratory for design purposes. Roads, airfields, water and sewer systems, and foundations for buildings, bridges and towers have been and are being observed at several locations in the Yukon and Northwest Territories.

All information collected, much of it from actual construction projects and therefore directly applicable to local permafrost problems, is used to improve design and construction practice. A book, ***Permafrost: Engineering Design and Construction***, based on the knowledge and experience gained from such studies, was written by Canadian engineers, including DBR staff, under the auspices of the NRC Associate Committee on Geotechnical Research. It consists of a series of chapters on the most important aspects of permafrost engineering.

Heat Flow through the Ground

Two dangers confront buildings in the North: frost heave can cause foundations to lift and permafrost can melt and cause them to settle. If either occurs a structure can be destroyed. Proper design of foundations can guard against these dangers.

An ongoing project is seeking to improve the capability to model the thermal behaviour of the ground using the computer. One- and two-dimensional heat-flow models of soil freezing and thawing have been developed and applied to estimate the effects of snow cover on ground temperatures.

Thermal computations require information on material properties. It is now possible, using new equipment, to measure the thermal conductivity of soils in the laboratory and in the field. Information has been gathered on the seasonal variations in thermal properties in road embankments and in natural terrain.

Knowledge gained through this work has been used by designers and companies involved in northern development and the planning of pipelines.

Frost Action in Soils

The cost of frost damage to roads and runways is still high despite improvements in design and construction in recent years. The problem is that the frost susceptibility of materials, with respect to both frost heave and loss of strength in spring, cannot be predicted accurately in the laboratory.

A more complete understanding of the ice growth process in soils, particularly with regard to frost heaving, is needed. This has been emphasized in recent DBR studies. The change in the heaving force at the base of the ice lens — from initiation to completion — under a series of closely controlled freezing rates has received particular attention.

Problems of building on frozen ground are not unique to the North. Cold winters in many other parts of Canada cause seasonal ground freezing and frost heaving. Even pile or post foundation members, extending well below the maximum frost depth, may be heaved by adfreezing to the sides of the member. Studies in the Ottawa area and at Thompson, Manitoba, have produced valuable information on adfreeze forces and methods of reducing them.

Frost action in soils is a project of long standing at DBR, whose expertise is tapped by Canadian and U.S. regulatory bodies concerned with pipeline design and construction, and by other research institutions.

Ice Platforms for Arctic Offshore Drilling

Oil and gas drilling offshore in the Arctic is hampered by floating ice for much of the year. Even where there is a landfast ice cover available, its load-bearing capacity is usually exceeded by the weight of a drill rig. To develop sufficient carrying capacity, the thickness of the ice is increased by surface flooding with sea water. Over 20 wells have been drilled from such ice platforms.

When a thickened ice platform was first considered, DBR was asked by the Department of Indian and Northern Affairs to review the design. Later, after construction, DBR assisted in a monitoring program to measure deflections, temperatures and strains in the platform. These measurements confirmed that the platform behaved as predicted and provided an improved basis for future designs.

Sea Ice Engineering

For many activities in the North it is essential to know the thickness, behaviour and properties of ice. Determining whether floating ice sheets are safe to use as drilling platforms, bridges or airstrips, is an example of an ice engineering problem. Determining the reaction of a wharf to a moving ice sheet is another.

The strength and properties of ice are influenced by past weather conditions as well as those prevailing. Ice covers formed from "multi-year" ice — that which has existed for more than one year — differ from those formed by "first-year" ice. It is important to be able to differentiate between the two types and to be able to specify the properties of the ice covers in which they occur.

Ice forces are a major problem in the design of marine structures in the Arctic. Field investigations of ice behaviour and properties are establishing a better knowledge base for design. The action between tidal-influenced ice and a wharf at Nanisivik on northern Baffin Island was observed and preliminary measurements of ice loads were made. Loads were substantially lower than the design values used.

Ice rubble formation around built-up islands used for oil and gas exploration in the Beaufort Sea has been studied. This work has focused on the properties and characteristics of the rubble field and the way it transfers load from the surrounding ice to the islands. The Division has assisted the Canada Oil and Gas Lands Administration in assessing design proposals and in specifying monitoring programs to ensure safety.

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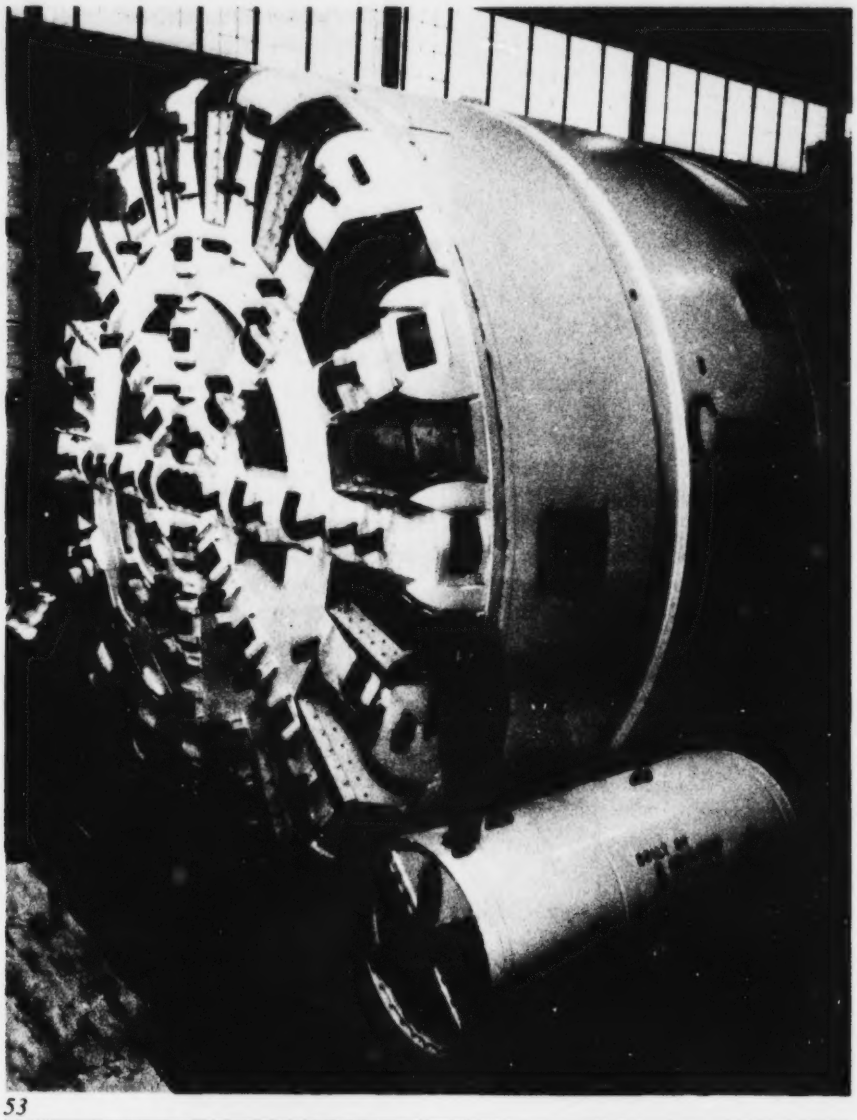

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51.
Offshore drilling from an ice platform in the Canadian Arctic. The thickness of the ice can be increased by surface flooding.

52.
Measuring ice cover thickness and depth of water where an iceberg has grounded in Lancaster Sound. This is part of DBR studies of ice forces on structures in the Arctic.

53.
Huge rock tunnel boring machine used in Nova Scotia mining (courtesy Lovat Tunnel Equipment Inc.).

Measurements of ice cover interactions with a small island in Lancaster Sound and atmospheric and oceanographic driving forces are being carried out jointly with Fisheries and Oceans Canada, Environment Canada, and groups from Britain and West Germany. Results are being used to develop models of ice response to environmental driving forces and models of ice interaction with the island, from which ice design loads can be derived.

DBR researchers developed an optical method (using binoculars with filters) to identify the different types of ice. Information on the growth and therefore the strength of first-year and multi-year sea ice was gained from participation in a joint project with Environment Canada, Energy, Mines and Resources Canada, and U.S. agencies concerned with the satellite surveillance of ice properties in Mould Bay. The Division has been helping to develop a simple method of predicting the growth of first-year sea ice by relating ice thickness to weather data in the Pond Inlet area.

Tunnelling

Part of the modernizing of the sewage treatment and collection facilities in Thunder Bay, Ontario, undertaken in 1976, called for a section of sanitary trunk sewer 3.3 km long and 2.16 m in diameter. The successful bidder proposed the use of a tunnel boring machine together with a segmented precast concrete tunnel lining, which would greatly reduce the amount of labour and material required. This was the first time such a technique was used in North America. Because the subsoil (mostly soft clay) was difficult to tunnel through, the Division was asked to participate in an instrumentation program to evaluate the tunnelling procedure and the performance of the complete tunnel. The trial was successful and the lining method is now generally accepted in North America.

During this project, it became evident that a Canadian manufacturer of tunnel boring machines (for use in soft ground) had exceptional design skills. NRC en-

couraged this manufacturer to develop new Canadian technology and to extend it to machines that could bore through rock. With the support of NRC and Supply and Services Canada, an experimental rock tunnel boring machine was designed and successfully tested at a large coal mine near Sydney, Nova Scotia. Based on the success of the prototype, a 7.6-m diameter machine was built. Put into operation in 1983, the machine can drive access tunnels faster and more safely than is currently being done in Canada. A spin-off from the project is the design and construction of a completely new machine that can disassemble, transport and reassemble the tunnel boring machine within the confines of a mine.

Acoustical Tests

For the effective control of sound in a building, designers must know the properties of the acoustical systems and materials they plan to use: those intended to reduce the transmission of sound from one space to another (walls, floors, windows and doors) and those meant to absorb sound within a space (tiles and drapery).

A reverberation room is used to measure three important acoustical quantities: the absorption coefficient of an acoustical material, the sound transmission loss of a building partition, and the sound power output of a noise source. It offers a convenient and economical way of averaging a quantity over all angles of sound incidence.

DBR has tested many systems and products to evaluate their acoustical properties under controlled conditions. Laboratory tests permit the acoustic evaluation of small changes to specimens under test and provide the information necessary to verify that proposed systems are satisfactory. Field tests of similar systems uncover possible problems that would occur in practical situations.

The results of laboratory tests are used to certify to bodies such as CMHC that a proposed system has the required acoustical properties. A series of tests may provide general design information which is then published by DBR. Designers may use this information to select the best combination of cost and performance.

Model Studies in Acoustics

Acoustical experiments can be carried out using small-scale models and high-frequency sound sources. The results can then be used to predict the behaviour expected in full-size rooms at lower frequencies.

DBR has two model chambers in addition to its two full-size reverberation rooms. One, a 2.5:1 scale model of the largest reverberation room, is used to study the nature of sound fields in a reverberation room and how changes to the sound field influence the measurement of sound absorption. The other, a 4:1 scale model of the sound transmission suite, is used to study the influence of changes in room size and shape on the measurement of sound transmission through partitions. Research results are used by standards-writing bodies to make test methods more precise and accurate.

Aircraft and Traffic Noise

Complaints from building occupants about aircraft and traffic noise have become increasingly common in urban areas. In response to a request from CMHC, the Division undertook studies of the problem.

With the cooperation of CMHC and Transport Canada, a test house was constructed near Ottawa International Airport to assess the effects of different types of outside walls on the amount of aircraft noise penetrating the house. The study was supplemented by laboratory measurements of sound transmission loss through windows, invariably the part of the envelope with the lowest resistance to noise.

A computer was used to make measurements around roadways and near highway barriers, sometimes in cooperation with the Ontario Ministry of the Environment.

On the basis of this work and that of other researchers, guidelines were prepared for CMHC for the proper design of houses close to airports and major roads.

Footstep Noise

A vexing problem for building occupants is the noise generated by footsteps. Floor assemblies have been tested for many years using a standard impact machine comprising five steel hammers driven by a motor. Unfortunately there is poor correlation between the test results and actual footstep noise.

There is considerable controversy over how best to solve this problem. Modified test procedures and modified impact machines have been evaluated. The noise generated by a machine developed at DBR compared well with footstep noise for a number of lightweight floors.

Some of the results have been used to evaluate proposed new test methods prepared by ASTM. The work will continue to be a basis for improved standards and will lead to a new test method that more accurately evaluates floor systems.

Vibrations of Structures

Structures vibrate when subjected to dynamic loads such as wind, earthquakes, elevators and traffic. If the vibrations become worrisome or annoying to the occupants, remedial measures may be called for. Examples are vibrations of houses from road and rail traffic, swaying of high-rise buildings during strong winds, and shaking and possible cracking of basement walls from blasting operations. These often result in requests for assistance.

To devise effective solutions to such problems, the dynamic properties of the structure must be determined. This is done by installing sensitive vibration monitors and recorders in the structure. DBR has determined the dynamic properties of a high-rise building in Toronto, of the Lions Gate Bridge in Vancouver and the Daniel Johnson Dam on the Manicouagan River in Quebec.

Data from these projects were furnished to the engineers for use in their design work, and published in the technical literature. The methods contained in the National Building Code to determine the dynamic properties of buildings were also assessed using information gained from the investigations.

Linking Design and Construction

More attention is being paid nowadays to the design-construction process, from planning through to completion of the project. DBR's aim is to "improve the product" through the application of building science to this process.

The principal means used by DBR to explore failures in the complex design-construction process has been to investigate problems in the field and relate them to construction techniques and building elements. Conducted within a framework of building science principles, these studies provide information that will lead to improvements in the process.

Some building envelope problems occur because design has not adequately reflected the extremes of the Canadian climate. Problems may be intensified in buildings that require high relative humidities such as museums, art galleries and structures housing computer systems or swimming pools. Faulty designs for windows and heating systems, poorly installed insulation, leaking roofs and cracked foundations are also cause for concern. All of these "failures" demonstrate the need for better cooperation and understanding between designers and contractors.

Studies of the design-construction linkage are usually done by experienced research personnel who can apply information from a variety of technical fields and translate the results of controlled laboratory experiments into building practice.

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54.
DBR has conducted tests on the Daniel Johnson Dam to determine whether additional turbine intake tunnels can be excavated by blasting without damage to the dam structure.
55.
Deterioration of masonry wall on swimming pool building caused by air exfiltration, condensation and frost action.
56.
This fellow doesn't mind the cold but the Canadian climate demands careful attention to building science principles.

TECHNICAL INFORMATION FOR BUILDERS

There are many "players" in the building industry, all with their own particular needs. The list includes architects, engineers, manufacturers, contractors, homeowners, and university and college teachers. This diversity of disciplines and interests makes the transfer of building technology somewhat difficult. Compounding the challenge in recent years has been a proliferation of new building materials and practices and an ever-increasing volume of information worldwide. As building science encompasses almost every facet of pure and applied science, the industry requires assistance in matching available technology with the specific problems encountered.

Publications

The Division of Building Research reached a milestone in technology transfer with the publishing, in late 1983, of ***Building Science for a Cold Climate*** (John Wiley & Sons Canada Limited). This comprehensive textbook on the science of building contains the store of knowledge required to understand the design and performance of building enclosures for a cold climate. It will be indispensable to universities and colleges.

A second major work was the book ***Roofs***, published in 1980. Drawing on the extensive knowledge of the author and his colleagues in the Division as well as other sources, the book focuses on design, application and maintenance. It is of interest to designers, builders, roofers and teaching institutions.

On the building practice side, 54 Building Practice Notes and 78 Canadian Building Digests were published. Digests are the DBR publications most widely used by the industry. Published in leaflet form, they are later compiled in bound volumes. Three volumes, each with an index, are now available, incorporating Digests No. 1-200.

About 120 Building Research Notes were published. Over 600 research papers were published in scientific and technical journals and several hundred test reports prepared in response to requests from industry.

Many publications are "best sellers," including the "Manual on Metric Building Drawing Practice" (68 000 copies sold) and Building Practice Note No. 23 on Urea Formaldehyde Foam Insulation (57 700 copies distributed). The most popular Digest was "Airtight Houses and Carbon Monoxide Poisoning" at over 29 000 copies. The all-time leading publication is Housing Note No. 11, "The Condensation Problem – Here are the Causes and Cures," originally published in 1963. About 200 000 copies have been requested, french and english combined, since 1973.

Building Science Seminars

Almost every year since 1964 the Division has organized and presented a series of building science seminars in major cities across the country. These educational opportunities have been extremely popular with the industry; annual attendance has averaged about 1000 in the last five years. Formal presentations by DBR staff and guest lecturers in the morning are followed by discussion in the afternoon. Attendees value the chance to gain first-hand insight into specific building problems, while DBR benefits from the practical experience of these leaders in the industry. The two most recent seminars featured "Exterior Walls" (1982) and "Condensation in Houses" (1983). The series, now called "Building Science Insight," usually begins in October and continues until early December. The proceedings are published early in the new year.

Building Science Clinics

In 1981 the Division began a series of informal sessions with members of individual architectural firms who expressed a desire to consult building scientists about problems they were encountering. Sessions were held in Edmonton, Calgary and Quebec City.

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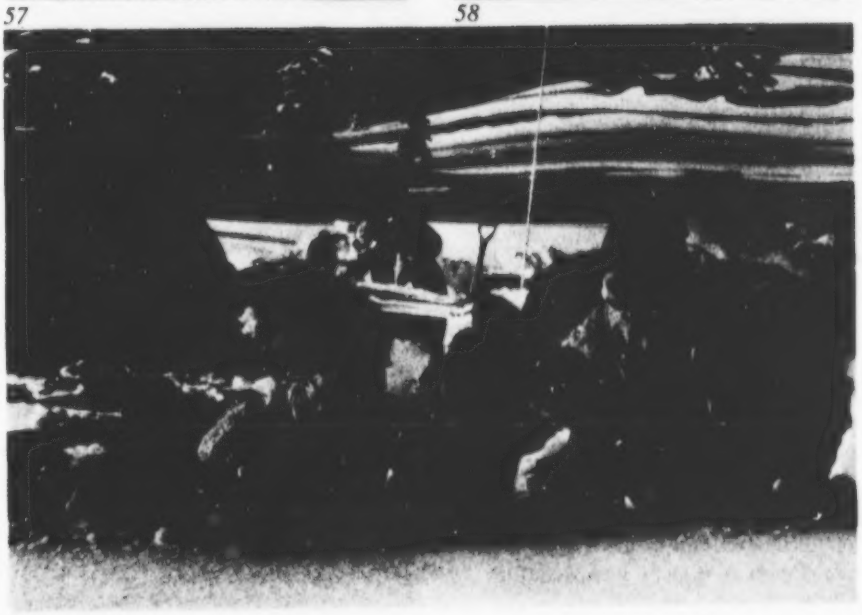

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57. 58.
Efflorescence (left) and spalling (right) of brick masonry, often seen on buildings in Canada, were among the subjects covered at a recent building science seminar sponsored by DBR.

59.
Training courses are given for professionals responsible for avalanche safety in danger zones.

60.
Trouble-shooting on the job site: three heads are better than one.

Lectures and Conferences

From time to time DBR staff give special lectures in post-secondary institutions throughout Canada. B.C. regional staff have given televised lectures on matters related to the National Building Code as well as seminars on calculating residential energy requirements. The Division sponsors and contributes to numerous conferences and seminars each year as a regular part of the technology transfer process.

Technical Inquiries

Answering technical inquiries is a major activity. About 15 000 to 20 000 are received annually through letters, telephone calls or personal visits. Although inquiries are a responsibility of the Technical Information Group, every researcher is, to a certain extent, an information officer. Indeed many inquiries are referred to researchers for advice in their area of expertise. Inquiries concerning the National Building Code and the National Fire Code are answered by the Codes and Standards Group.

Site visits often result from an inquiry; over the ten-year period hundreds of visits were made. Avalanche hazards to transmission lines, frost heave of pipelines, fires on merchant ships, floor vibrations in apartment buildings and condensation problems in houses were some of the concerns.

Architects, engineers and designers frequently come to seek technical advice on such problems as wall design, roofing materials, insulation and energy requirements. The Prairie Regional Station is a leader in the design of low-energy houses, making the staff popular with builders and homeowners.

Personal consultation is especially useful at the design stage, before trouble occurs. But DBR staff are also prepared to assist with trouble-shooting and to offer advice on remedial measures. This contact with practitioners keeps staff abreast of building problems and concerns; where an inquiry has identified a serious or widespread problem, the Division may prepare a report so that the industry as a whole can benefit.

Part of DBR's mandate is to provide a technical research service to CMHC, which has responsibility for certain matters relating to housing in Canada. Besides doing laboratory studies, DBR has advised on new building materials, answered housing inquiries, taken part in CMHC seminars and technical committees, and provided technical information for many CMHC publications.

DBR Library

The largest and most complete collection of building science literature in Canada is housed in the DBR library. While the library is a prime resource for research staff, it is open to the building industry as a whole. Each year about 3000 loans and photocopies of papers are requested by outside agencies, institutions and individuals. Through computerized literature searching, the library, a branch of the Canada Institute for Scientific and Technical Information (CISTI), now has ready access to scientific and technical literature not in its own holdings.

CODES AND STANDARDS

The National Building Code and the National Fire Code are model codes that are made available by the National Research Council for adoption by provinces or municipalities. NRC provides the means to produce and update these codes through two of its "Associate Committees" whose members are from outside the Council. All secretariat and administrative services, as well as research and technical assistance, are provided by the Division of Building Research.

The last ten years, during which three new editions of the NBC and two editions of the NFC were issued, have seen a number of significant changes. One change, involving both codes, was the introduction in 1973 of additional safety requirements in high-rise buildings. DBR studies had shown that the time required to evacuate a tall building during a fire often exceeded the available time. Because of the "chimney effect" that occurs in winter, resulting in the upward spread of smoke, it appeared that existing measures for containing a fire on a lower storey might not prevent the movement of smoke upward through stair and elevator shafts. This created the potential for very dangerous conditions for occupants of upper stories. New measures were introduced, including the control of elevators by keyed switches, smoke venting of each floor area, two-way voice communication between each floor and the central alarm and control station in buildings over 37 m high, sprinklering of certain areas, pressurization of stair and elevator shafts, and a provision for dividing buildings vertically into two or more isolated zones.

In the 1975 edition of the NBC, a number of changes were made in Part 9, Housing and Small Buildings. Some of the major ones concerned seasonal house (cottage) construction, access to public buildings for the physically disabled, the use of safety glass in exterior doors and bathtub enclosures, and the requirement for wall bracing in stud frame walls when interior or exterior cladding does not provide sufficient rigidity. Other changes were the inclusion of span tables for roof trusses, and new fireplace requirements regarding the proximity of combustible materials. In the same edition there were also major changes in the requirements of Part 3, relating to accessibility for disabled persons, fire safety, fire alarm and detection systems, and exit doors.

In 1978, requirements for atriums — large open areas that run upward several stories — were included in the NBC as they had become popular in the design of shopping centres and hotels. There was a need for regulation to limit the risk of involvement of more than one floor level in the event of a fire and to provide for adequate egress facilities assuming the worst conditions.

"Measures for Energy Conservation in New Buildings" was published in 1978 after a lengthy development and review process. Some 1600 written comments were received by the code secretariat from a diverse audience that included architects, engineers, building officials, manufacturers and homeowners. These "measures" were the prescriptive type. "Performance-type" requirements based on energy budgets, however, are the long-term objective of the Standing Committee on Energy Conservation. An updated version of the publication was issued in 1983.

The 1980 edition of the NBC brought some new fire protection measures. These included a complete review of fire alarm and fire detection systems, rationalization of requirements for the fire separation of occupancies and tenancies, relaxation of certain requirements in institutional buildings, and a requirement for access routes for fire departments. An extension of access requirements for physically disabled persons to apply to all types of office buildings was also added.

All provinces as well as the Northwest Territories and the Yukon use the NBC directly or base their requirements on it. In some cases the NBC is adopted by reference, with or without revisions to suit local conditions or satisfy local legal requirements. Some provinces have not adopted their own code and in these cases many municipalities have based theirs on the NBC. The widespread use of the NBC gave impetus to the formation, in 1978, of the Provincial Advisory Committee on the NBC; it advises the Associate Committee on the NBC when provincial interests are affected.

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LOOKING AHEAD

Research and development will continue to play a dominant role in Canada's economy in the coming years. The construction industry can expect continued support from the Division of Building Research in developing technology for the challenges that lie ahead.

Effective communication of building science information and technology will be a priority. Research will be carried out on the use of the computer for this task as well as for other purposes that serve the interests of the construction industry.

The search for greater energy efficiency will go on, as will the battle for better building envelopes to ward off the intrusions of Canada's cold climate. With the trend to improved airtightness in buildings, air quality research will command more attention.

Continuing development in the North will intensify research and development for engineering in cold regions and DBR will be giving particular attention to questions related to construction.

The excellent facilities at the Fire Research Field Station will provide new opportunities to help reduce the relatively high death and property toll from fire in Canada.

The durability of building materials, a critical element in building performance in Canada's climate, will continue to receive strong emphasis.

With an aging building stock, the country is facing major renovation and rehabilitation needs. Through studies of materials, test methods, renovation methods, building performance and building economics the Division will assist the industry in meeting these needs.

Building codes and standards will continue to be major elements in the control of quality of construction in Canada. Provision of technical information and expertise for their development will be emphasized. The Division will also actively participate in the evolution of the codes and standards system as it adjusts to more effectively serve the needs and interests of the country.

Finally, the Division will maintain the expertise it has developed over the years and continue to forge strong links with the industry it serves.

61.
Accessibility for the disabled is an important requirement in public buildings.

62.
The National Building Code now contains fire safety requirements for atriums.

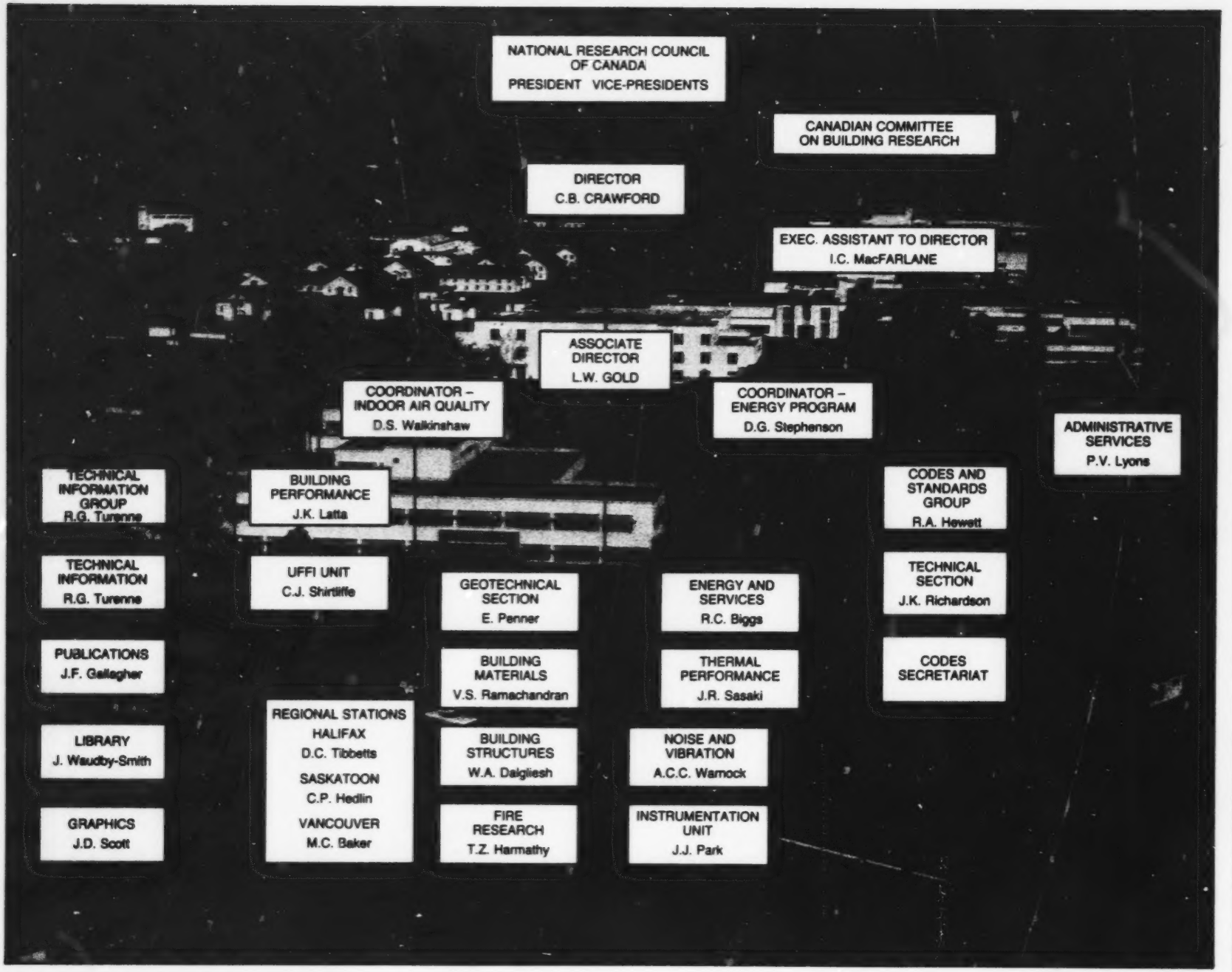
THEN AND NOW

Left to right, the three directors of the Division of Building Research, National Research Council of Canada, photographed in 1974: Robert F. Legget, 1947-1969, Neil B. Hutcheon, 1969-1974, and Carl B. Crawford, 1974 to date.

Robert F. Legget, who had been Professor of Civil Engineering at the University of Toronto, took up his duties as the first Director of DBR in August 1947. He served for 22 years until his retirement in 1969, leading the Division through its major formative period during which staff grew from one to 240.

Neil B. Hutcheon came to the Division from the University of Saskatchewan where he had been Professor of Mechanical Engineering. He was one of the first to do research in what is now called "building science." He served as Assistant and then Associate Director from 1953 until 1969 when he became Director.

Carl B. Crawford joined the Division in 1949. He was Head of the Geotechnical Section before becoming an Assistant Director in 1969. He succeeded Dr. Hutcheon as Director in 1974. He is assisted by Lorne W. Gold as Associate Director.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Field Stations

Fire Research Field Station
c/o Division of Building Research
National Research Council of Canada
Ottawa, Ont. K1A 0R6
(613) 256-3138 (Carleton Place, Ont.)

Rogers Pass Field Station
Division of Building Research
National Research Council of Canada
P.O. Box 2759
Revelstoke, B.C. V0E 2S0
(604) 837-2435 (Revelstoke)
(604) 837-6274 (Rogers Pass)

INFORMATION ON DBR PUBLICATIONS

Free Publications

Copies of reports in the following series published by DBR can be obtained free by writing: Publications Section, Division of Building Research, National Research Council of Canada, Ottawa, Ontario, K1A 0R6.

Canadian Building Digests – four-page summaries of technical subjects of current interest to the building industry.

Building Practice Notes – short reports on techniques and problems associated with current building practice. Published on an irregular basis.

Building Research Notes – brief reports designed for immediate publication of research results. Published on an irregular basis.

Canadian Building Abstracts – annual compilation of abstracts of building technology articles published by DBR and Canadian periodicals. Published in December.

DBR Research Program – annual list of research projects, with notes on each research section. Published in March.

BR News – newsletter published three times a year, in March, July and November.

Priced Publications

Research papers are published in journals and technical literature throughout the world. Reprints are available at a small charge.

Books, committee reports, seminar and conference proceedings, translations of foreign works and special publications are published on an irregular basis. Most are available at a small charge.

List of Publications

DBR issues an annual List of Publications. During the year three supplements – one every four months – keep readers abreast of new publications. Those wishing to receive the annual and supplements regularly may write requesting that their name be added to the mailing list. There is no charge.

Mailing Lists for Various Series

There are separate mailing lists for Canadian Building Digests, Building Research News, Canadian Building Abstracts, and Building Practice Notes. Readers can receive publications automatically in any of these series by requesting that their name be added to the appropriate mailing list(s).

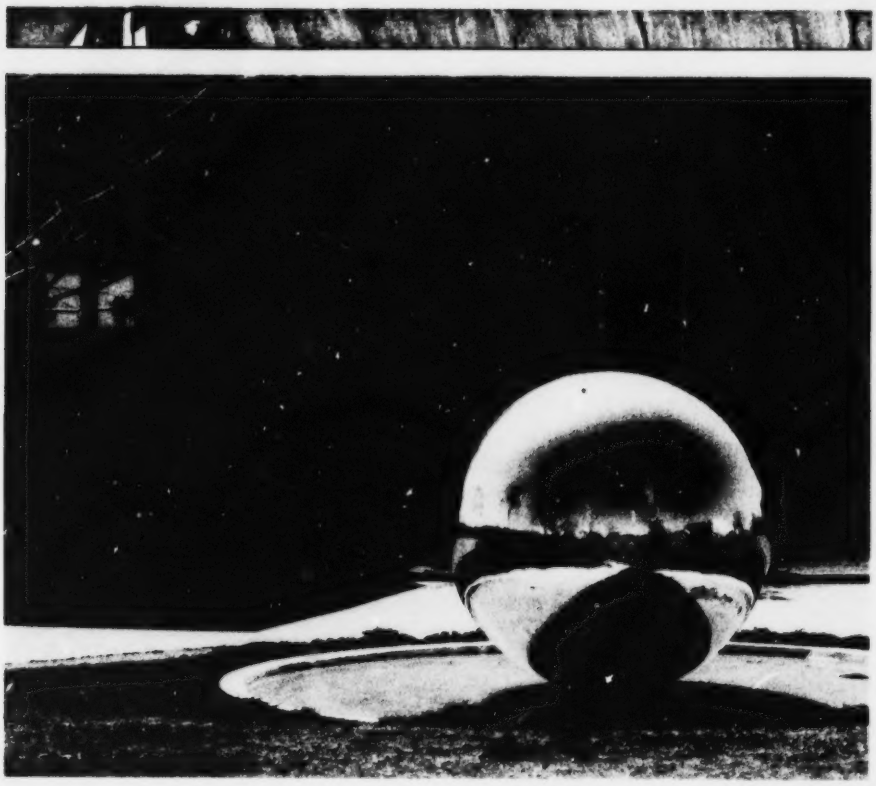
Codes Publications

Documents pertaining to various codes and standards for buildings are processed by the Division's Codes and Standards Group. These priced documents include:

National Building Code (NBC) of Canada
Administrative Requirements for the Code
Supplement to the NBC
Canadian Plumbing Code
Building Standards for the Handicapped
National Fire Code (NFC)

An NBC/NFC newsletter is published quarterly, and is free of charge.

Information on these documents should be requested from Codes and Standards Group, Division of Building Research, National Research Council of Canada, Ottawa, Ontario, K1A 0R6.



Glistening globe in front of NRC's Montreal Road headquarters.